

**Residential Combustion Venting Failure
A Systems Approach**

Project 5

Make-up Air Supply Remedial Measures

**RESIDENTIAL COMBUSTION VENTING
FAILURE - A SYSTEMS APPROACH**

RESIDENTIAL COMBUSTION VENTING FAILURE
A SYSTEMS APPROACH

FINAL TECHNICAL REPORT

PROJECT 5

MAKE-UP AIR SUPPLY REMEDIAL MEASURES

Prepared for:

The Research Division
Policy Development and Research Sector
Canada Mortgage and Housing Corporation

Prepared by:

Scanada Consultants Limited
Scanada Sheltair Consortium

July 30, 1987

Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

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Principal Consultants:	John C. Haysom Scanada Consultants Limited
	David Eyre Saskatchewan Research Council
Project Manager for CMHC:	Don Fugler
CMHC Scientific Authority:	Jim H. White

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PROJECT 5: MAKE-UP AIR SUPPLY REMEDIAL MEASURES

ABSTRACT

A research project was conducted to investigate make-up air supply issues in the context of combustion venting problems. The project was one three projects conducted by a multi-disciplinary team of scientists and engineers to investigate remedial measures for combustion appliances. The research represents one sub-project in an overall project to investigate combustion venting remedial measures for several types of combustion appliances. The results of the tests indicated that the provision of additional supply air is not likely to be effective if the supply air is introduced unaided through an envelope opening. It is only likely to be effective if a supply air fan is used with a capacity at least equal to the total capacity of all exhaust equipment it is attempting to counteract. It was also recommended that the discharge from such a supply air fan is likely to create fewer thermal comfort problems if introduced in a normally unoccupied area such as the furnace room.

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This project was funded by the Canada Mortgage and Housing Corporation and the Panel for Energy Research and Development (PERD), but the views expressed are the personal views of the authors, and neither the Corporation nor PERD accepts responsibility for them.

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EXECUTIVE SUMMARY

The investigation into general air supply issues was classified as follows:

- *general air supply issues*
- *effectiveness of air supply openings*
- *effectiveness of air supply fans*

All tests were conducted in a 1960's vintage Saskatoon bungalow owned by SRC. For the purposes of this project, the house was equipped with -

- *a range top barbeque with integral exhaust fan rated at 165 L/s*
- *a range hood exhaust system rated at 130 L/s*
- *a clothes dryer, tested at 58 L/s exhaust capacity (cold) and 52 L/s (hot) at 0 Pa*
- *an air supply fan rated at 118 L/s*
- *various means of creating and closing air supply openings in various places in the envelope.*

The different pieces of exhaust equipment were operated singly and in a number of combinations with each other and in a number of combinations with the air supply fan and the air supply openings.

The results of the tests indicated that the provision of additional supply air is not likely to be effective as a remedy for pressure-induced spillage of combustion products if the supply air is introduced unaided through an envelope opening of any size likely to be considered practical. It is only likely to be effective if a supply air fan is used and if that fan has a capacity at least equal to the total capacity of all exhaust equipment it is attempting to counteract. The discharge from such a supply air fan can be introduced essentially anywhere in the house, but is likely to create fewer thermal comfort problems if introduced in a normally unoccupied area such as the furnace room.

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INTRODUCTION

This report describes one of seven sub-projects of an overall project entitled -

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- which was carried out for Canada Mortgage and Housing Corporation by the Scanada Sheltair Consortium Inc. A summary of the overall project is provided in Appendix A.

This is one of several final reports on the fifth sub-project, "Remedial Measures", which was concerned with research on remedial measures for various types of combustion equipment experiencing combustion venting problems. This report deals with remedial measures related to the supply of make-up air.

There are many possible causes of combustion venting failure. Often the failure is not pressure-induced at all. For example, the chimney might be partially or totally blocked. In such cases, remedial measures are usually available and are usually obvious; e.g. unblock the chimney. However, in the case of pressure-induced spillage, the choice of a remedial measure is seldom so clear. There has been a tendency to fall back on some form of make-up air supply; but there has been little data on the reliability of such measures and little information on how to relate the type and size of make-up air provisions to the cause of the pressure-induced spillage. This project therefore concentrated on research on remedial measures for pressure-induced spillage and included both make-up air supply measures and alternatives to make-up air supply.

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MAKE-UP AIR SUPPLY REMEDIAL MEASURES

The research on make-up air remedial measures was conducted by the Saskatchewan Research Council (SRC) under subcontract to the Scanada Sheltair Consortium. SRC's detailed reports are appended as follows:

Appendix B - excerpt from a progress report providing the rationale for SRC's choice of measures to investigate

Appendix C - SRC final report

The results reported in the final report are summarized here.

SRC's work was not oriented only toward specific measures, as was the other research centres', but also included investigation into general air supply issues. Thus their work could be classified as follows:

- general air supply issues
- effectiveness of air supply openings
- effectiveness of air supply fans

The work consisted of a large number of detailed tests. It could be said that the various tests were designed to arrive at what was already fairly standard engineering knowledge. However, as this knowledge has been largely overlooked or ignored in the context of regulating combustion venting, there was significant value in conducting tests which -

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- placed this knowledge in a residential combustion venting context, and
- were done very carefully so as to eliminate extraneous variables and thus make the results convincing.

All tests were conducted in a 1960's vintage Saskatoon bungalow owned by SRC. It is of typical wood frame construction and has an equivalent leakage area of 520 cm² (as determined by testing in accordance with CGSB Standard CAN/CGSB-149.10-M). For the purposes of this project, the house was equipped with -

- a range top barbeque with integral exhaust fan rated at 165 L/s
- a range hood exhaust system rated at 130 L/s
- a clothes dryer, tested at 58 L/s exhaust capacity (cold) and 52 L/s (hot) at 0 Pa
- an air supply fan rated at 118 L/s
- various means of creating and closing air supply openings in various places in the envelope.

The different pieces of exhaust equipment were operated singly and in a number of combinations with each other and in a number of combinations with the air supply fan and the air supply openings. The tests are too numerous to detail here; however, the more significant results can be summarized as follows:

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Pressure Distribution

With the interior doors open and the furnace circulation fan not operating, any pressurizing or depressurizing effect of an exhaust or supply fan or supply air opening was felt uniformly throughout the house on a virtually instantaneous basis. Thus, the location of supply air provisions and the final point of delivery of the supply air appears to be not critical. Therefore, it need not be near either the exhaust equipment or the combustion equipment and its location can be governed by other considerations such as thermal comfort. This, of course, would not apply to houses with isolated or sealed furnace rooms.

Effectiveness of Air Supply Openings

With the 165 L/s range-top barbeque exhaust fan operating, opening a 152 mm air supply opening (a 29% increase in the equivalent leakage area), either a simple opening or ducted, had no significant effect on the level of depressurization in the house. The same was true with the 52 L/s (hot) dryer exhaust operating.

Effectiveness of Air Supply Fan

Operation of the 118 L/s air supply fan was effective in overcoming the depressurizing effect of the 58 L/s (cold) dryer exhaust but could only partially offset the depressur-

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izing effect of the 165 L/s range-top barbeque exhaust, leaving a level of depressurization great enough to be of concern from a combustion venting point of view. This residual depressurization would have been even greater in a more nearly airtight house.

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CONCLUSIONS

The provision of additional supply air is not likely to be effective as a remedy for pressure-induced spillage of combustion products if the supply air is introduced unaided through an envelope opening of any size likely to be considered practical. It is only likely to be effective if a supply air fan is used and if that fan has a capacity at least equal to the total capacity of all exhaust equipment it is attempting to counteract. The discharge from such a supply air fan can be introduced essentially anywhere in the house, but is likely to create fewer thermal comfort problems if introduced in a normally unoccupied area such as the furnace room.

SRC Project Manager David Eyre also gave considerable thought to the strategy that would be best suited to controlling a supply air fan and concluded that -

- start-up should be triggered by a latching pressure switch sensing the indoor/outdoor pressure difference and
- shut-off should be controlled by a timer which would run the fan for several minutes after start-up.

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A P P E N D I X A

OVERALL PROJECT SUMMARY

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OVERALL PROJECT SUMMARY

The project reported on here was designed to expand on previous studies of the problem of incomplete venting of combustion products from heating appliances in order to approach a more nearly comprehensive understanding of the extent and nature of the problem in the Canadian housing stock. This project, which was carried out for Canada Mortgage and Housing Corporation by the Scanada Sheltair Consortium Inc., consisted of the seven sub-projects described below.

PROJECT 1 COUNTRY-WIDE SURVEY

Spillage detectors were installed on the draft hoods or barometric dampers of gas and oil furnaces and water heaters in 937 houses spread throughout the Vancouver, Winnipeg, Toronto, Ottawa and Charlottetown regions. The detectors were left in place for approximately 2 months in late winter.

Of the gas heated houses surveyed, 10% had experienced prolonged and unusual amounts of combustion gas spillage and 65% had experienced either short duration start-up spillage or prolonged spillage of small amounts of combustion gas. Of the oil heated houses, 55% had experienced significant spillage of high temperature combustion gas, but some of these spillage events may have been of only short duration.

Preliminary analysis indicates that spillage problems seem to be related to the following house or heating system characteristics:

- Winnipeg houses (believed to be more nearly airtight due to extensive use of stucco)
- pre-1945 houses
- post-1975 houses
- one storey houses
- exterior chimneys
- masonry chimneys with under-sized metal liners
- houses with three or more exhaust fans
- houses with two open masonry fireplaces
- poorly maintained heating appliances

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PROJECT 2 MODIFICATIONS AND REFINEMENTS TO THE FLUE SIMULATOR MODEL

FLUE SIMULATOR, a detailed theoretical computer-based model of the combustion venting process had been developed for CMHC prior to this project. It is intended for use as an aid in understanding the mechanisms of combustion venting failure and the circumstances that give rise to them. The modifications undertaken in this project were intended to make the program easier to use and to allow it to model a wider variety of furnace/flue/house systems. The modifications included -

- o refinements to algorithms
- o more efficient operation of the program
- o modelling additional features and system types
- o user-friendly input and output

The modified model was validated against field test data and used to investigate a number of issues.

A separate developmental version of the program, called WOOD BURNING SIMULATOR, was successfully developed to model the combustion and combustion venting process in wood stoves and fireplaces.

PROJECT 3 REFINEMENT OF THE CHECKLISTS

A procedure for identifying and diagnosing combustion venting failures had previously been developed for CMHC - the Residential Combustion Safety Checklist. This project provided an opportunity to refine the checklist and develop variations of it suitable for a variety of possible users such as furnace service personnel, air sealing contractors, homeowners, etc. Early in the project, it was decided to separate the identification procedures from the diagnostic procedures. This allowed the process of identifying houses with potential for combustion venting problems to remain relative simple and allowed the diagnostic process to become more complex since it would only be used on houses where the extra effort would likely be worthwhile. Thus the original backdraft checklist has grown into five separate tests/procedures -

Venting Systems Pre-test

- a quick, visual inspection procedure which identifies a house as either unlikely to experience pressure-induced spillage or requiring further investigation

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- a detailed test procedure for determining to what extent the combustion venting system of a house is affected by the envelope airtightness and operation of exhaust equipment, perhaps the clearest descendent of the old backdraft check-list.

Chimney Performance Test

- a simple method of determining whether a chimney is capable of providing adequate draft

Heat Exchanger Leakage Test

- a quick method of determining if the heat exchanger of a furnace has a major leak

Chimney Safety Inspection

- a visual check for maintenance problems in the chimney system

These tests/procedures are all presented in a manual entitled "Chimney Safety Tests". Full trials of the procedures were carried out on the case study houses investigated in Project 6.

PROJECT 4 HAZARD ASSESSMENT

Although little was known at the outset of this project about the frequency of combustion spillage, even less was known about how much of a health hazard such spillage represents. Therefore this sub-project was included to investigate the real nature of the health and safety risk associated with venting failures. The work was divided into five tasks -

1. Review of current knowledge on pollutant generation due to improper venting of combustion appliances (literature review).
2. Development of a computer program to predict levels of various pollutants under various combustion venting failure scenarios.
3. Acquisition and calibration of a set of instruments required to measure the various pollutants at the levels predicted by the computer model.
4. Monitoring pollutant levels in problem houses identified in the Country-wide Survey (Project 1) using the instruments acquired in Task 3.
5. Analysis of the results of Task 4 to arrive at an overall assessment of the health hazard represented by combustion venting failures in Canadian houses.

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The results indicate that, in most houses, one would rarely encounter acute, immediately life-threatening concentrations of pollutants as a result of combustion spillage from furnaces or water heaters. However, chronic health risk due to low level, long term exposure to pollutants, particularly NO₂, may be a more significant problem which requires further investigation. High levels of CO do not seem to be caused by the problems which cause spillage and thus occur in spillage events only as a result of coincidence.

PROJECT 5 REMEDIAL MEASURES

Remedial measures for pressure-induced combustion venting problems were identified and researched for a number of different types of combustion appliances.

The remedial measures identified for FIREPLACES were:

Spillage Advisor

- This is an adjustable volume alarm triggered by a combination of particulate and CO detectors and intended to be mounted on the front of the mantle or on the wall just above the fireplace.

Airtight Glass Doors Combined With An Exterior Combustion Air Supply Duct

- The research indicated that conventional glass doors are not nearly airtight and do little to separate the fireplace from the house's pressure regime. Prototype doors using special glass, heavier than normal steel frames and special sealing techniques were fabricated and installed and tested. It was found that these doors increased the level of house depressurization required to cause prolonged spillage from the fireplace from 3 Pa to 22 Pa. It is estimated that the installed cost would be \$600. Further research on the effect of airtight doors on temperatures within the fireplace and flue and the possible hazard to surrounding combustible materials is required.

The remedial measures identified for GAS-FIRED APPLIANCES were:

Spillage Advisor

- This could be similar to the fireplace spillage advisor but would be triggered by a heat probe mounted in the dilution port of the appliance. The heat probes inves-

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tigated could also be used to trigger other remedial measures discussed below.

Draft-inducing Fan

- A paddle-wheel-type fan mounted in the vent connector was found to increase the level of house depressurization required to cause irreversible spillage from a naturally aspirating gas furnace from 7 Pa to more than 20 Pa.

Draft-assisting Chamber

- A chamber surrounding the appliance's dilution port and extending downwards contains combustion products flowing out of the dilution port and prolongs the period before they are actually spilled into the room. It was expected that the chamber would also use the buoyancy of the contained combustion products to assist the flue in developing upward flow and thus would increase its resistance to house depressurization; however, the results obtained with the prototype tested did not live up to expectations. It is expected that modification of the design and testing with a furnace/flue/house combination more prone to pressure-induced spillage will improve this aspect of the chamber's performance.

The research on remedial measures for OIL-FIRED APPLIANCES indicated that stable backdrafting is unlikely to be a problem with oil-fired appliances since the pressure generated by the burner blowers is able to rapidly overcome backdrafting due to house depressurization and initiate upward flue flow. However, this pressurization of the flue system is what accounts for the start-up spillage associated with oil appliances and it is the duration of this spillage that remedial measures must address. The measures identified were:

Solenoid Valve

- By delaying the start of combustion until the burner has had a chance to overcome backdrafting and initiate upward flue flow, the solenoid valve reduces the duration of spillage but does not eliminate it altogether.

Draft-inducing Fan

- A fan, similar to that described above under gas appliances, mounted in the flue pipe downstream of the barometric damper is not needed to overcome backdraft-

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ing since the burner blower can do this. However, it does relieve pressurization of that portion of the flue pipe upstream of itself and hence reduces spillage from that portion. There can still be spillage from the downstream portion; but, since that portion does not include the barometric damper, it is easier to seal.

Elimination of the Barometric Damper

- Provision of a well-sealed flue pipe without a barometric damper is one obvious way to reduce spillage. However, elimination of the barometric damper exposes the burner to the full chimney draft and disturbs the combustion process of conventional burners. Therefore this procedure must include replacement of the conventional burner with a high pressure burner which is less influenced by flue pressure. Provision of an insulated flue liner is often included as part of this measure.

The work on MAKE-UP AIR SUPPLY remedial measures was less directed towards specific measures but served to clarify a number of general air supply issues. It indicated that the provision of additional supply air is not likely to be effective as a remedy for pressure-induced spillage of combustion products if the supply air is introduced unaided through an envelope opening of any size likely to be considered practical. It is only likely to be effective if a supply air fan is used and if that fan has a capacity at least equal to the total capacity of all exhaust equipment it is attempting to counteract. The discharge from such a supply air fan can be introduced essentially anywhere in the house, but is likely to create fewer thermal comfort problems if introduced in a normally unoccupied area such as the furnace room.

The knowledge generated in the remedial measures research and already available to Consortium members was synthesized into the draft Remedial Measures Guide, a manual intended to be a decision-making guide for tradesmen and contractors who have identified pressure-induced spillage problems in houses with vented fuel-fired appliances and want to know how best to remedy these problems. It is designed to accompany the Venting Systems Test. Although the draft Guide is not yet comprehensive and in some cases describes procedures which have not been thoroughly field tested and/or approved by regulatory authorities, it is hoped it will stimulate thought and discussion and improve current trade practices.

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PROJECT 6 PROBLEM HOUSE FOLLOW-UP

Twenty of the houses identified in the country-wide survey as experiencing the worst combustion spillage problems were visited with the following objectives:

- to categorize and quantify the nature of venting failures
- to isolate contributing factors
- to collect field data on venting failures for use in the flue simulator model validation
- to measure the frequency and quantity of spillage in problem houses
- to measure the approximate impact on air quality of venting failures in houses
- to evaluate the effectiveness of the chimney safety tests in diagnosis of failures and identification of remedial measures
- to evaluate communications techniques
- to evaluate remedial measures under field conditions

In most of the houses, there were several factors that were assessed as contributing causes of the combustion spillage problem - thus confirming the "systems" nature of the problem. It is also worth noting that, in many houses, although the spillage observed was indeed pressure-induced, it occurred at quite low levels of house depressurization because the chimneys were only able to generate very weak draft due to some problem such as a blocked or leaky flue. The main problem in these cases, therefore, was not depressurization but weak chimneys.

PROJECT 7 COMMUNICATIONS STRATEGY

As the survey revealed that the problem, while substantial, is not epidemic in proportion, there is no need to create widespread alarm in the general public. A communication strategy has been drafted with this in mind. It places emphasis on motivating the heating and housing industries to be aware of the combustion venting problem and its causes and to make effective use of the diagnostic tools and preventive and remedial measures developed in this project.

OVERALL PROJECT SUMMARY AND CONCLUSIONS

The project has gone a long way towards meeting its original objectives and has significantly advanced the state-of-the-art in

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this field.

It has led to improved understanding of the combustion venting process and confirmed the "systems" nature of the failures that lead to combustion venting problems.

It appears that a significant portion of the Canadian housing stock has potential for combustion venting failure to occur on a regular basis. In most cases, this is unlikely to lead to immediate life-threatening pollution levels, but long term chronic health hazards could be a problem; however this latter concern requires further investigation before any definite conclusion can be reached.

A number of techniques are available for identifying houses prone to combustion venting failure and for diagnosing the causes of such failure. There are also available a number of measures for preventing combustion venting failure in new houses and for remedying it in existing houses. A communication strategy has been drafted for conveying these techniques and measures to relevant people in the housing and heating industries and for encouraging them to make use these tools.

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A P P E N D I X B

RESEARCH PLAN FOR MAKE-UP AIR SUPPLY

Excerpt from January, 1986 Progress Report

Progress Report 1. Scanada-Sheltair Study

Consisting of the Proposed SRC Work
Plan and an Evaluation of the Consumers
Gas Study.

Prepared for:
Scanada-Sheltair Consortium Inc.

Prepared by:
D. Eyre
Saskatchewan Research Council
15 Innovation Blvd.
Saskatoon, Saskatchewan
S7N 2X8

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1. THE CONCEPT OF SYSTEMIC DESIGN

In addition to the material required by Scanada-Sheltair I have included some discussion of concepts. This is mainly to get my own ideas in some sort of order. Most of the ideas are not new, though some of them may be of value.

In some of my papers over the last four years I have tried to promote an awareness of the house as an interacting system. More recently I have pointed out that, in dealing with this system, we have got ourselves into a cascading sequence of cause and effect - or a cascading sequence of problems and solutions. Thus, backdraft prevention is a consequence of ventilation which is a consequence of airtight construction which is etc. etc.

In effect, we have established a serial system, in which each component is to some extent dependent on other components. This is not good design; it is better to try to establish parallel design concepts such as those on which the automobile is based (eg. the steering system operates independently of the braking system, etc.)

The braking system of an automobile contains three concepts that could usefully be incorporated into the Scanada-Sheltair Study:

- No system can be made absolutely safe or foolproof. An acceptable design is one which functions with an acceptable perceived risk of failure.
- The essentials of the design and operation should be made minimally interactive, so that if the component fails it does so with minimum risk and minimum upset to other components.
- Interactive design is permissible, but should be limited to non-critical aspects of operation (eg. power assist on a braking system is a non-critical feature dependent on some kind of power drive).

The material produced so far in the Scanada-Sheltair Study indicates that we are headed towards the kind of parallel system advocated above. This direction is assisted by the structure of the Study, in which different agencies will try to evolve self-sufficient solutions for the components they are dealing with.

2. WHERE DO WE NOW STAND, CONCEPTUALLY?

There is no significant history of ventilation or combustion air supply technology in residential design, and it is only the recent trend towards airtight housing that has forced us to focus on this technology. Traditionally, house air management has contained three main elements:

- The house is leaky enough to meet the air supply needs for ventilation and combustion.
- Ventilation technology, such as it is, consists in exhausting noxious air out of the house at selected points. There has been no significant attempt to develop controlled ways of introducing air into the house.
- Since air leakage is distributed more or less uniformly over the building envelope, it assists the process of fresh air distribution throughout the house interior and thereby places less demands on the operation of the air distribution system (where present).

These things have occurred by a process of evolution rather than one of engineering design. This is not to say that they are no good; they satisfy the needs of the traditional house system for which they were evolved. However, they do not satisfy the needs of the house systems we are now developing. In particular:

- The airtight or sealed house eliminates most of the infiltration air that, traditionally, has served as a source of combustion air supply and ventilation air. Both functions involve air supply, and therefore the airtight house creates a need for an air supply technology that has very little historical development to guide us.
- Similarly, the airtight or sealed house lacks the general movement of air that existed in the traditional leaky house (not only by virtue of reduced air leakage, but also by virtue of the more isothermal conditions resulting from higher levels of insulation, more efficient windows, etc.). A greater burden is therefore placed on the air distribution system of the house, and there is evidence that these systems - even the latest designs - are sometimes incapable of handling these new requirements.
- Because of the reduced air exchange rate of the house, there can exist a competition for air supply between the various air-using systems (fireplace, furnace, fans, etc.) whose operations all depend on exhaust flow. This can result in the flue starvation problems that are central to the Scanada-Sheltair Study.

The Scanada-Sheltair Study assigns priority to the first and last considerations, namely air input technology and the control of competitive interactions between air-using systems. At this juncture it is useful to make the point that controlled air distribution may also have a part to play in the eventual solution.

3. WHERE DO WE NOW STAND, TECHNICALLY?

The first encounter between building science and the consequences of airtight construction occurred in the Energy Showcase of Homes in Saskatoon in 1980. These were the first truly airtight houses containing air combustion systems. The earlier Saskatchewan Conservation House had avoided such combustion systems and its air management system was designed only to remove stale air from the house and replace it with fresh air. Air was removed from noxious areas (kitchen, bathroom and laundry) and manifolded through a single exhaust pipe to the exterior, through a primitive heat exchanger design which extracted heat from the stale exhaust air and passed it to the incoming fresh air supply.

In the Saskatoon Energy Showcase the air combustion systems (furnace and DHW heater) added a new dimension to the problem: can a controlled ventilation system be regarded also as a combustion air supply system? In the opinion of the local gas inspectorate the answer was "no" - the combustion air supply had to separate, and as far as possible it had to be isolated from interactions with the ventilation system. The wisdom of this ruling has been consistently advocated by SRC since 1980, and the consequences of trying to avoid it are now confronting us in several instances.

This gas inspectorate ruling came at a late stage of the project design. Thus, at a late date, the consultants and builders had to find a way of dealing with the ruling at short notice. Two answers were found: the first was to use a forced draft furnace (only one USA design was available at the time); the second and more popular answer was to enclose the furnace and DHW heater in a fairly tightly sealed room with its own combustion air inlet, designed in accordance with CGA Codes.

The experience of the Saskatoon Energy Showcase has been generally positive. The furnace room has achieved its designed objective of separating the ventilation systems from the combustion systems. There has been no evidence of flue icing, though the University of Saskatchewan has found low air temperatures (close to freezing) in some furnace rooms. This, as pointed out in a BETT report by Eyre (attached), is a consequence of a too-small furnace room, and indicates a need for further R&D in furnace room design.

The Apple Hill Project, in Ottawa, copied the furnace room approach shortly afterwards and experienced flue icing problems which were evaluated both by CMHC and SRC (Eyre: *ibid*). In SRC's view the furnace room must carry a reduced risk of flue icing, since the room has access only to exterior air rather than the more humid air from the house interior. Temperature effects, which are significant, can be overcome by good furnace room design - in evidence of which there are several problem-free furnace rooms in Saskatoon.

In spite of all this, there has arisen in the East a generally negative view of furnace rooms. Those who have them in Saskatoon remain advocates, but from the East there are all sorts of undocumented criticisms, based

on such things as cost effectiveness. One may be permitted to ask: what is the cost effectiveness of the increased safety resulting from effective isolation of the furnace?

In the author's view the furnace room has been criticized mainly on the basis of poor examples of design, stemming from inadequate development of the concept. Given proper design and development, the furnace room could provide an answer to some of the problems being addressed in the Scanada-Sheltair Study. The cost-effectiveness aspect has been overstated; some kind of furnace enclosure already exists in most developed basements, and little extra effort and cost are required to convert it into a reasonably sealed room. Such a room need not be hermetically sealed; the level of sealing should be such that the furnace finds it easier to draw air through the combustion air supply system rather than from the house interior.

I shall now get off this particular soapbox and move to other technical issues.

Experiences from the HELP Program:

The Hatch Report provides indirect evidence of combustion system backdraft (44 cases of carbon monoxide poisoning). Post-dating this report, and of considerably more relevance to the Scanada-Sheltair Study, is the recent experience from the Saskatchewan Home Energy Loan Plan Program (HELP). In the last 18 months at least 11 authenticated cases of furnace backdraft have been identified in houses built under this Program. Hanson, in a recent report to the CHBA Technical Review Committee, suggested that the actual incidence may be far higher. The HELP houses are built to moderately high standards of airtightness and insulation, and from tests conducted around 1983 it is clear that many builders are achieving very high levels of airtightness (less than 0.15 acph natural) at modest incremental cost. In the problem houses the backdrafting has been attributed to interaction with the ventilation system. In some cases the ventilation system may be a single fanned exhaust manifolded to bathroom, kitchen and laundry (this is not advised). In other cases the system may be a double-fanned inlet-exhaust unit that has not been properly balanced.

Important note:

On two occasions Saskatchewan Power Corporation (administrators of HELP) have asked SRC to conduct research on the problem houses, but have not been able to provide the necessary funds. Accordingly, SRC has asked BETT to fund this research, but BETT has declined. The problem is still live, and Scanada-Sheltair may wish to consider incorporating some of the problem houses in the present study (see my later recommendations).

Evidence of unbalanced flow:

Monitoring conducted by Besant on the Saskatchewan Showcase houses indicates that many of the installed air-to-air heat exchangers have

failed to achieve their claimed performance (60% to 80%) and are actually performing at the 40% to 50% level by virtue of unbalanced flows.

In 1984-85 a study was conducted by SRC on a 50-condominium project in Yellowknife. The study was prompted by moisture problems, which were initially thought to be due to overpressurization caused by imbalanced flows on the heat exchangers. Subsequent site measurements by SRC showed that the heat exchangers were actually depressurizing the house and helping to reduce the moisture exfiltration.

These two cases have been pursued in some depth by SRC. It has been discovered that, in many instances, heat exchanger manufacturers are claiming that their systems are balanced, purely on the basis of in-factory tests which take no account of the varying flow resistance conditions occurring at site. A factory-balanced flow system is unlikely to behave the same at site. The risk of unbalanced flows is considerably more pronounced in simple inlet/exhaust systems assembled in situ, since such systems lack even the nominal factory balancing that is performed on some heat exchangers.

Through these and other cases, SRC has been exposed to the problems of in-situ flow balancing, and has come to the conclusion that it can be achieved only with difficulty. The mechanical installers will need to acquire considerable new skills, and this must be backed by some form of quality control. The criterion for balancing can be questioned: should a system be balanced on the basis of flow, or pressure, or some more complicated combination of the two? The answer is not as simple as might appear at first sight.

4. THE CONSUMERS GAS STUDY

This is reviewed under a separate heading since it is a specific requirement of SRC's sub-contract.

4.1 Outline of the Study

This study was initiated by the Ontario government, but was expanded at an early stage to include extra features that were of interest to the BETT program. The originally planned research consisted of two phases: the first being to develop and prove a technique for inducing controlled backdraft conditions and quantifying these conditions; the second was to apply the technique to 36 houses in a quasi-statistical investigation of backdrafting processes, including an investigation of the competing effects of fans and fireplaces. All houses in the study were equipped with naturally aspirating gas furnaces.

BETT added another phase to this work, to deal with two concerns related to its recently published Air Sealing Manual. The first was: how tightly can one seal a house before creating air supply problems? The second was: given that a backdrafting problem can be produced by house sealing, what advice can one give to sealing contractors regarding remedial air supply options?

These questions were investigated on two houses in two series of tests. The first series consisted of an investigation of the effects of sealing. A range of tests, including backdrafting tests developed earlier, were conducted on the test houses. Sealing techniques were applied to half of the envelopes (upper or lower) and the tests were then repeated. The remainder of the envelopes was sealed and the tests again repeated.

The second series of tests was concerned with remedial air supply systems to overcome backdrafting problems. A panel of experts was assembled in Toronto in August 1984 to identify and select the various design options. The air supply design was split into two components: the way in which air was introduced through the building envelope (inlet) and the way in which it was delivered to the furnace (delivery). Inlet options consisted of a single inlet port, a double port, a wind-averaging arrangement utilizing two or four ports distributed around the four walls of the house, and finally a roof inlet exposed to the same wind regime as the flue cap. The delivery options consisted of an opening remote from the furnace, one very close to the furnace, one attached to the combustion air inlet, one coupled to the cold air return plenum, a U-tube (cold trap) variation and an induced fan draft system.

Various combinations of inlet and delivery options were to be studied. Specific tests were identified for specific combinations. The tests included investigations of cold air pooling, backdrafting effect, wind sensitivity, seasonal sensitivity, and air supply competition from fans and fireplaces.

* "Consumers Gas Chimney Venting Performance Study" J. Timusk, K. Selby, A. Seskus/Centre for Building Science for Ontario Ministry of Energy and Building Energy Technology Transfer Program, Energy Mines and Resources, Canada

4.2 Results of the Study

Consumers Gas has now completed all phases of the work, but has only reported on the first two phases. The report on the third phase, which is of greatest interest to the Scanada-Sheltair Study, has been delayed by problems in interpreting the data. Currently, BETT is collaborating with Consumers Gas with the intention of producing the third-phase report in the near future.

The first phase was completed in 1984 and was reported jointly by Consumers Gas and the University of Toronto (sub-contractors on this project). There were three main findings:

- The technique of inducing backdraft and measuring it under controlled house depressurization was found to be usable.
- The measurement of fan characteristics by the difference between two airtightness tests - one with the fan operating and one with the fan not operating - was found to be workable, though subject to substantial errors by virtue of the small pressure effects.
- Wind was found to have a large influence on the measured backdrafting performance - the variability due to wind changes being of the same order as the effect being measured.

The second phase, dealing with backdraft and related tests on 36 houses, was reported recently, in draft form, by the University of Toronto. The main findings were as follows:

- The most adverse pressure that can be resisted in cold chimney conditions during start-up is termed the Critical Vent Establishment Pressure (CVEP). The measured mean value over the test houses was 6.2 Pa with a standard deviation of 2.1 Pa.
- The most adverse pressure that can be resisted under hot steady-state conditions is termed the Hot Vent Reversal Pressure (HVRP). The measured mean value was 23.9 Pa with a standard deviation of 8.37 Pa.
- In only a small proportion of houses can one expect to find a combination of fans and fireplaces sufficiently potent to cause backdrafting problems. Furthermore, the worst-case combined operation of these facilities will occur infrequently.
- The variability of wind effect, as observed in Phase I, was again confirmed. However, it was observed that wind generally assists the venting of chimneys.
- Fireplaces were found to be stronger than fans in terms of depressurizing effect.
- Air tightening increases the risk of venting failure, though the increased risk is still very small.

4.3 SRC's appraisal

Phase III has the greatest application to the Scanada-Sheltair Study, and it is disappointing that the report on this Phase is not yet available. The report may become available during the course of this study, but this does not answer the immediate needs. SRC has already approached Consumers Gas in an attempt to elicit the main findings from Phase III, but it is clear that Consumers Gas is reluctant to commit itself even to general comments at present.

The CVEP and HVRP data give a useful quantification of backdrafting pressure criteria, and the specific case data may provide Scanada-Sheltair with useful real-life data against which to test the FLUESIM model. With SRC's and CMHC's assistance, there should be no problem in accessing the data through Consumers Gas or the University of Toronto.

In SRC's opinion, the most significant findings of the study (to date) relate to the observed wind effects - particularly when these effects are compared with the magnitudes of the observed backdrafting criteria. A windspeed of 3 m/s (approx 7 mph) has a dynamic head of 0.2 Pa, equal to the measured mean CVEP. Similarly, a windspeed of 6.1 m/s (approx 13.5 mph) has a dynamic head of 24 Pa, close to the measured mean HVRP. Thus, it would seem that modest wind speeds - 7 to 13.5 mph - can produce pressure effects of sufficient magnitude to cause backdrafting. Under typical residential zoning, with surrounding trees and neighbouring houses, it is known that pressure loading on a house can achieve local values as high as three dynamic heads, thereby amplifying the wind's capability to induce backdrafting.

This should come as no surprise; the thought was expressed during the Consumers Gas planning meetings that, under certain wind conditions, all houses can potentially suffer backdrafting effects - and probably do.

Wind effects are expected to play a highly significant role in practically all aspects of the Scanada-Sheltair Study. Under the action of a prevailing wind there will be a complicated pressure variation, of considerable magnitude, over a house envelope. This is not important in a leaky house with a distributed pattern of air leakage points, but in a sealed house with air inlet and air exhaust openings, each of these openings will respond to the local pressure field. An inlet or exhaust vent is therefore affected not only by windspeed, but also by wind direction. This has important consequences for vent design and location. For example, if a kitchen fan is provided with an exhaust vent and a make-up fresh air vent, it is important to locate the two vents so that they are exposed to similar wind regimes - otherwise the system might experience undesirable wind effects. This factor was recognized in the planning stage of the Consumers Gas Study, and was translated into two air supply configurations designed to be wind-insensitive. The performance of these configurations has not yet been reported.

5. PROPOSED PLAN OF ACTION

5.1 Objectives

Under the terms of reference supplied by Scanada-Sheltair, SRC will confine itself to the investigation of three systems:

- Kitchen exhaust,
- Clothes dryer exhaust,
- House air supply.

SRC would actually like to conduct a broader-ranging investigation, including such things as bathroom fan, central vacuum system make-up air (95 to 110 cfm) and a more extensive range of measured parameters, but it is felt that this would not be achievable within the time scale and cost of the sub-contract.

5.2 Considerations affecting the design of the work plan

1. Following the discussion in section 1, it is proposed to base the experimental investigation on two concepts:

- The main objective will be to develop and test individual systems that are essentially non-interacting, in the sense that they do not rely on the operation of other systems in the house. Such systems are potentially simple, easier to install, and more easily comprehended by the installer and the homeowner. They allow the parallel systems approach which is believed by SRC to be the best basis for design.
- The secondary objective will be to develop and test interactive designs, in which the operation of one system is affected by the operation of another.

2. Under the heading of non-interactive design, it is proposed to treat each of the three systems independently (ie. kitchen, dryer and house air). This represents a considerable departure from past practices, in which kitchen, laundry and bathroom vents comprise the exhaust side, and the house air supply comprises the inlet side of one large air management system. It places far less demands on the design of the house air supply system, which can then be treated much like any other inlet/exhaust arrangement.

If each system is to be independent, then it must have its own independent exhaust/inlet arrangement (a strategy that now appears to be accepted in the R2000 program). Thus each system will have two ducts associated with it. To minimize uncontrolled air leakage through these ducts it is desirable to have some kind of damper arrangement. Figure 1 shows a proposed twinned damper system, in which the dampers of the exhaust and inlet are activated by the exhaust fan. This has the advantages of simplicity and reliability, and would appear to be a good way to proceed, subject to detailed experimental considerations given later.

3. When these systems have been installed and tested, they can then be modified for the second part of the tests, which concentrates on designs with interactive elements or greater complexity. This presents a problem: an interlock, for example, is simply an electrical switch, which does not really need to be tested. The switch will admittedly control the on-off combinations of the various systems, but the depressurizing effects of these combinations can accurately be deduced from the tests conducted on the original systems. Therefore, the issue at this stage is to identify the most useful and effective way to proceed after conducting tests on the non-interacting systems. It is believed that the obvious ways to proceed will become evident during the work, and it is therefore proposed to submit an interim report after the first tests, including recommendations regarding the second set of tests.
4. Regarding the kitchen fan system, the Jenn-Air fan is gaining popularity and its characteristics are considerably different from those of the conventional designs. It is therefore proposed to test both a Jenn-Air design and a conventional design.
5. Regarding the clothes dryer system, it is felt to be unrealistic to concentrate on an air supply system integral to the dryer body. It is not a practice that one would advocate as a retrofit measure, partly because of technical problems, potential for impairing the operation of the dryer, and possible warranty implications. In previous retrofit projects SRC has provided air supply inlets close to the dryer, and these have not presented problems. It is therefore proposed to use this option.
6. Regarding the house air system, the best approach is still to make use of the house air distribution system as a way of distributing the incoming fresh air throughout the house. As noted above, if all the other air handling systems in the house are designed to act independently, then the demands placed on house air exchange become less stringent: it should not be necessary to deal with odours, pollutants or excess humidity from bathroom, kitchen and laundry. The role of the house air system is reduced to the simple one of maintaining good air quality under non-extreme conditions. Given that the system will consist of an inlet and an exhaust duct, connected in some way to the air distribution plenum, the main design problem then centres on the method of control. Experiments on this system will be directed mainly at the consequences of various control options: humidistat, interlock with furnace fan motor, etc.

5.3 Proposed work plan

The work will be conducted on the SRC test house. This is a conventional house, purchased on the open market in a residential area in Saskatoon. It was built in 1954 and is a single-storey platform-built unit on a full concrete basement. The house is unoccupied and has been equipped with an extensive instrumentation package, including a weather station, a

permanently installed airtightness test rig and a computer-controlled data acquisition and storage system. The house differs from conventional in only two respects: the furnace and DHW heater are contained in a sealed furnace room, the door of which can be opened to simulate normal operation; the basement walls and floor are lined with polyethylene to control moisture movement from below grade. The various experimental facilities in this house will be used to enhance the range of experimental work on the Scanada-Sheltair study at minimal cost.

The following work will be conducted:

1. Three non-interactive air systems (kitchen, clothes dryer and house air) will be installed with individual exhaust and inlet ducts, an exhaust fan and a twinned damper system as shown in figure 1. Two types of kitchen fan - Jenn Air and conventional - will be included in all main tests.
2. The pressure-flow characteristics of each will be determined. Direct measurements of pressure and flow will be conducted as far as possible. If this is unsuccessful, it is proposed to adopt the method used by the University of Toronto in the Consumers Gas Study, based on changes in the airtightness test characteristic. If the make-up flow through the various fan inlets is judged to be insufficient, a new fan unit will be installed and tested.
3. Depressurization effects will be studied under the following combinations:
 - One vent system operating at a time, under three conditions: inlet duct closed, inlet duct open but un-fanned, inlet duct open and fanned (if a fan is considered necessary). Special variations will be considered for the house air system and its co-operation with the furnace fan.
 - Two vent systems operating at a time, with inlet duct closed and then opened but unfanned.
 - All three vent systems operating simultaneously, under the same conditions as above.
 - All the above combinations will be tested under three furnace conditions: furnace inactive and chimney cold; furnace and chimney in steady state operating conditions; furnace cold and isolated from house by closing door on sealed furnace room.

As far as possible, the depressurization tests will be conducted with low wind conditions. Measurements will consist of: pressure difference inside to outside in the region of the furnace and the activated device(s); change in this pressure difference caused by operation or non-operation of the device(s); flows through the devices; effect on CVEP and HRVP using U of T method.

4. If possible and convenient, wind effects will be studied. The details will emerge during the above experiments and are not clear at this stage.

5. The results of the above tests will be analysed and will be used to establish the best approach for operating and testing an interlock system (in this house an interlock may not be strictly necessary). An interim report will be submitted, giving the findings to date and including a proposed course of action regarding the design and testing of further systems involving greater complexity or interaction.
6. When this proposal has been accepted (with or without client modification), SRC will proceed with tests on an agreed basis. In the event that the new systems require electrical interlocks or some interference with the operation of the furnace system, SRC will consult with gas and electrical inspectorates to establish what is acceptable under the existing codes.
7. The findings of the entire task will be set down in a report, satisfying the clients requirements for quality reporting. Six copies will be submitted to Scanada-Sheltair, together with an unbound master and an unformatted version of the report on diskette.

5.4 Costs and schedule

The costs and schedule stipulated by Scanada-Sheltair are acceptable. SRC will submit a more detailed response on these points if necessary

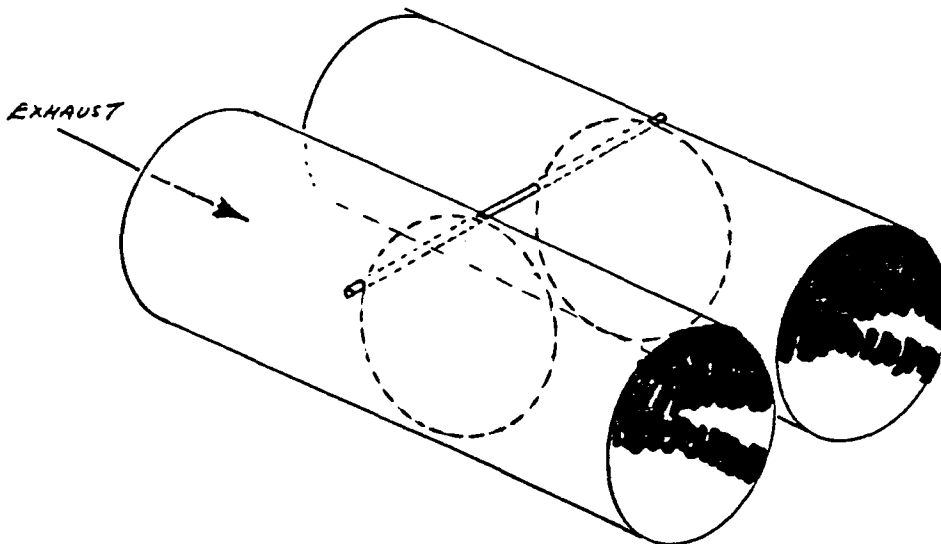


Figure 1. Proposed twinned damper arrangement

6. GENERAL RECOMMENDATIONS

SRC generally agrees with the structure and details of the proposed study, but in the light of information given earlier in this document, SRC would like to see the inclusion of:

- studies on wind effect,
- studies on the effectiveness of the furnace room concept,
- studies on the effectiveness of the air distribution system when used as a component of the house air system.

RESIDENTIAL COMBUSTION VENTING FAILURE - A SYSTEMS APPROACH
PROJECT 5: MAKE-UP AIR SUPPLY REMEDIAL MEASURES

A P P E N D I X C

RESEARCH ON REMEDIAL MEASURES -
REMEDIAL MEASURES FOR MAKE-UP AIR SUPPLY

SRC April, 1986 Report



Saskatchewan
Research Council

THE EFFECT OF EXHAUST FANS AND REMEDIAL MEASURES
ON HOUSE DEPRESSURIZATION

by

T. Hamlin and B. Gray
(Shelter Research Inc., Saskatoon)

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Ottawa, Ontario

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1. INTRODUCTION

This report is submitted to Scanada-Sheltair Consortium Inc. in partial fulfillment of a contract between the Consortium and Saskatchewan Research Council. The Consortium is currently engaged on a series of projects under the general title of "Residential Combustion Venting Failure - A Systems Approach", the broad objective of which is to advance the state of the art concerning the venting of combustion appliances in houses.

The work described in this report falls under Project 5, and is concerned with the potential impairment of combustion venting caused by the operation of the various exhaust systems found in a typical house (eg. ventilation fans, clothes dryer exhaust, central vacuum systems, etc.). Such exhaust systems lower the internal house pressure - including the pressure in the vicinity of the combustion furnace - and under certain conditions the effect may be large enough to impair the proper venting of the furnace flue. The effect is known to occur in some houses with higher-than-average levels of airtightness, where the various exhaust systems must compete for a limited air supply - but there is also evidence that it can occur occasionally in houses of normal construction with moderate to low levels of airtightness.

This report is therefore concerned with the depressurizing effects of selected house exhaust systems, and with the effectiveness of remedial measures designed to moderate these depressurizing effects. Such effects are dependent not only on the specific exhaust system, but also on the characteristics of the house used in the experiments. Thus, if the findings are to have general application, they must be expressed in a form that can conveniently be extrapolated to various houses with differing characteristics. The experiments have been designed with this in mind, and the results have been subjected to minimal processing - leaving the more detailed processing, analysis and extrapolation to the Consortium.

3. TEST FACILITIES AND EQUIPMENT

3.1 The test house

The tests were conducted in Saskatchewan Research Council's Test House, in Saskatoon. This is a conventional house of 1966 construction. It is a platform-built single-storey house on a full concrete basement, with a plan area of 101 m² (see figures 1 and 2). The basement is undeveloped and the house has been neither modified structurally nor retrofitted in any way. The house has no fireplace or stove.

For general experimental purposes the house has been provided with a tightly-sealed furnace room, housing a Lennox G80 natural gas furnace (110,000 Btuh) and a 25-gallon Woods domestic hot water heater. The room is provided with a door and a combustion air supply duct from the south wall. The house can be returned easily to normal configuration by opening the furnace room door and closing off the combustion air duct. In addition, the entire basement floor and wall has been covered with 6-mil polyethylene, primarily to eliminate uncontrolled moisture entry. The house is normally operated with all interior doors (except the furnace room door) and heating duct regulators removed, and this configuration was maintained throughout the described series of tests.

The house is provided with an extensive instrumentation package, including over 200 thermocouples, humidity recorders, pressure tapings and a permanently-mounted air depressurization test rig conforming to the design originally developed by NRC/DBR (Saskatoon). Referring to figure 1, the test rig is mounted in a boarded section of window at location F. The back yard of the house contains a standard meteorological station, including a wind speed/direction sensor at a height of 5 m.

In the authors' view, none of the in-built experimental features should significantly affect the findings of this study.

3.2 House modifications for this study

To minimize damage to the house, the vent openings required for this study were achieved by removing two window sections and replacing them with plywood boards containing vent openings. Referring to figure 1, two 152 mm openings were installed in window B for tests on the dryer and furnace, and two in window K for tests on kitchen exhaust equipment.

3.3 Exhaust systems used in the study

The following equipment was obtained for this study:

- An "Air King" 400-series range hood, 2-fan, 275 cfm (130 L/s) rated.
- A "Jenn-Air" C-201 counter top model, 350 cfm (165 L/s) rated.
- A "Torin" GP 250 fan, 250 cfm (118 L/s) rated, for use in pressurizing the furnace area at start-up.
- A "Kenmore" HD clothes dryer.

The local distributors for Jenn-Air equipment have expressed an interest in this project (though regrettably not in terms of a discount) and gave valuable advice on how the Jenn-Air should be installed. A mock-up counter top installation was fabricated, and the Jenn-Air and its ducting were installed according to the distributor's recommendations. The same mock-up assembly was used for mounting the range hood.

3.4 Details of ducting of exhaust appliances

The Jenn-Air was provided with 152 mm diameter ducting, consisting of 0.91 m of straight metal duct, 2.13 m of flexible vinyl duct and a further 0.91 m of straight metal duct connected a spring-dampered Jenn-Air outlet mounted in the kitchen window.

The range hood was also provided with 152 mm ducting, consisting of 0.3 m of straight metal duct, 2.13 m of flexible vinyl duct and a 0.91 m outlet section with a taped-open damper.

A 0.91 m section of 152 mm diameter straight metal duct was fitted to the dryer exhaust. This was coupled through a reducing section to 2.44 m of 102 mm flexible vinyl duct, connected to the permanent 102 mm dampered dryer outlet.

4. DETAILS OF THE TESTS

The following tests were conducted:

- Calibration of equipment;
- Determination of fan characteristics;
- Direct measurement of the depressurizing effects of the various exhaust appliances, operating either singly or in combination;
- Measurement of pressurization in the vicinity of the furnace due to a fanned inlet of exterior air, and with various operational combinations of other exhaust appliances;
- Airtightness tests in combination with the operation of various exhaust appliances;
- Investigation of remedial measures in the form of unfanned air inlets close to the exhaust appliance being tested, with simultaneous investigation of the effects of the cold air inlet on local thermal comfort level;
- Effects of wind on the depressurizing performance of exhaust appliances.

4.1 Calibration

A nozzle section with a 7.62 mm throat diameter, conforming to ASTM design specifications, was obtained for measuring flow rates. This was calibrated against a reference nozzle with accurately known characteristics, supplied by the University of Saskatchewan and gratefully acknowledged. The test nozzle characteristics were found to be close to design specifications.

4.2 Fan characteristics

A simple test rig was constructed for measuring the characteristics of the four fans used in the tests (see figure 3). Note that the inlet of the test fan was always open to ambient. The pressure drop across the test fans was measured with an inclined manometer connected between ambient pressure and a static pressure probe mounted about two duct diameters downstream of the test fan in the straight section of duct. Flow rates were determined from the pressure drop across the calibrated nozzle section, measured on a second inclined manometer. The control fan was used to set up different operating conditions.

Prior to each test the fans were subjected to a 10-minute warming-up run. The dryer fan characteristic was measured under two conditions, with heated and unheated exhaust.

4.3 Direct measurements of depressurization

The first objective of these tests was to measure the reduction in interior house pressure caused by the operation of the various exhaust appliances operating singly. The second objective was to measure pressure reductions with two exhaust appliances operating simultaneously. This was felt to be a useful investigation into the additive nature of depressurization effects - at worst, it would produce data that could be used to develop a model for combining the effects of two or more fans.

The house interior pressures were measured at two locations: close to the furnace and close to the appliance being tested. When testing the dryer a single pressure tap was located 2 m below grade and 2.5 m from both the dryer and the furnace. When testing the kitchen appliances the same pressure tap was used for the furnace location and a second pressure tap was located 2 m from the appliance and 1 m above grade.

Initially, an attempt was made to establish a stable reference pressure on the secondary arm of the inclined manometer, in the form of a sealed 4-litre jar. This produced anomalous measurements, presumably because it did not allow for pressure variations due to wind loading. This system was therefore abandoned and replaced with an exterior pressure tap conforming to the requirements of the CGSB Standard on Airtightness Testing. This consisted of a 4-way averaging system connected to taps located on the four sides of the house at a height of 2 m above grade. This was connected to the secondary arm of the inclined manometer through a 9-litre jar designed to damp pressure fluctuations.

Before the tests the house was prepared by deactivating the furnace and sealing all unnecessary openings, including all openings to appliances not being tested. The test fan was given a 10-minute warm-up run.

For the single-appliance tests the fan was sequentially switched on and off, and the steady-state pressure differences were measured at the described locations. The on-off sequence of measurements was repeated several times to allow statistical treatment and reduction of errors due to ambient changes. Ambient temperature, pressure, wind speed and wind direction were recorded at the house's meteorological station. Wind speed was determined from a 1-minute averaging of the cup anemometer signal. Wind direction was expressed in terms of the angle measured clockwise from North, as seen from above.

Initially, an attempt was made to investigate the effect of the furnace flue. The combustion air supply inlet to the furnace room was sealed, and the above sequence of tests was conducted first with the furnace room door closed, then repeated with the door open - the flue being unblocked during all tests. This had only a small effect on the measurements, suggesting that the flue makes only a small contribution

to the total air leakage performance of the house. The practice was therefore discontinued in later tests.

For tests with two exhaust appliances operating together, the experimental procedure was essentially the same as for the single tests, but a modified sequence was used, as follows:

- Both fans off,
- Fan 1 on,
- Both fans on,
- Fan 2 on,
- Both fans off.

For each test arrangement the above sequence was repeated several times to allow statistical treatment of the data.

For all the tests in this series, the pressure difference across the test fan was measured using the same arrangement as described in section 4.2. Knowing this pressure difference, it is possible to determine the flow rate through the fan fairly accurately by reference to the measured flow characteristics.

4.4 Pressurizing around the furnace at start-up

This remedial technique was suggested by the Consortium for inclusion in this study. When one or more exhaust appliances are operating they may inhibit the proper venting of the flue at furnace start-up. If exterior air is delivered by fan to the area around the furnace, it causes an increase in local pressure that could possibly overcome most of the inhibitory effects of the exhaust appliances. This local pressurization effect would be required for roughly one minute at the time of start-up.

Some consideration has been given to the various ways of tackling this problem experimentally. The required electrical control system would have to switch on the pressurizing fan simultaneously with the start of burn, and then switch off the fan some one or two minutes later. This is a fairly simple exercise in electrical control, which was discarded on the grounds that it would unnecessarily distract from the main thrust of this study.

It was considered impracticable to attempt to monitor pressure variations during the rapid transients at furnace start-up. It was therefore decided to concentrate on measurements of the steady-state pressure elevation around a non-operating furnace. It is believed that this information will be adequate for computer modelling purposes.

The experimental arrangement consisted of the Torin fan connected by 152 mm ducting to the basement window inlet, which was supplied with a bird screen and hood. The ducting consisted of 2.44 m of flexible vinyl

duct, running from the inlet to a 3.66 m section of straight Sonotube (cardboard) duct. The outlet of the Torin fan was positioned 0.5 m from the furnace face, and was directed vertically upwards. The pressure tap was located adjacent to the furnace dilution air entrance, approximately 1 m from the Torin fan outlet. This was connected to an inclined manometer, the other arm of which was connected to the exterior 4-way averaging system and the reservoir damper.

The pressure difference across all fan systems was measured for each test configuration, using the same arrangement as described in section 4.2.

For the tests, the objective was to try to simulate normal house operating conditions as closely as possible. The furnace door was opened, the flue was left unblocked, the airtightness test system was sealed off and all exhaust appliances were left in their normal operational condition (ie. not sealed).

The basic test sequence consisted of measuring the pressure difference across the manometer, and the pressure difference across operational fans, for various configurations in the following sequence, which was conducted twice:

- No fans operating
- Only the Torin operating
- Torin and dryer operating
- Torin, dryer and Jenn-Air operating
- Torin and Jenn-Air operating
- Jenn-Air and dryer operating
- Dryer only operating

The results were then analysed to determine the pressure shift caused by the Torin for different combinations of appliance operation.

4.5 Airtightness tests

Airtightness tests using the fan depressurization method were conducted under various configurations of exhaust fan usage. The blower door unit consisted of a Joy axial fan and an NRC nozzle section with a 102 mm diameter throat, previously calibrated by SRC. Nozzle pressure difference was measured by an inclined manometer to a resolution of 1 Pa. House pressure difference was measured by a second inclined manometer to a resolution of 0.25 Pa. The manometer was connected between the exterior 4-way averaging system, 2 m above grade, and a tap on the basement floor, 2 m below grade. The background pressure difference (with the blower door fan inoperative) was subtracted from all pressure readings. Data analysis was conducted in accordance with the November 1985 draft of the CGSB Standard on Airtightness Testing.

The house has a permanently-installed Dwyer manometer, reading the pressure difference through the ceiling to a resolution of 2 Pa. A small experiment was conducted with this device during one of the test runs.

4.6 Tests with remedial inlet air supply

The general test procedures were practically the same as those described in section 4.3.

For the Jenn-Air tests two air supply options were investigated: the first consisted of 3.65 m of flexible vinyl duct, 152 mm diameter, delivering exterior air to a location 0.2 m above the Jenn-Air counter. The second option consisted of a simple 152 mm diameter opening in the boarded kitchen window. Tests were conducted with various combinations of Jenn-Air on-off, air supply options and air supply open or blocked.

For the dryer tests the dryer was run with hot exhaust, and the air supply consisted of 2.13 m of 152 mm diameter flexible vinyl duct, delivering exterior air to a location 0.2 m from the dryer body. Four combinations were studied: dryer on or off, and air supply open or blocked.

Concurrently with these tests, an investigation of thermal comfort was conducted in the vicinity of the two appliances, to see if the use of cold exterior air caused any significant shift in comfort levels. This was done with a Bruel & Kjaer Thermal Comfort Meter.

4.7 Investigation of wind effect

The studies of wind effect were restricted to measurements of the performance of the Jenn-Air fan under various wind conditions. For these tests the house was arranged with the furnace room door open, the furnace flue unblocked, the combustion air supply vent closed, the dryer off and the damper operating normally, all inlet vents sealed, and the blower door sealed.

Measurements were conducted with a repeated sequence of Jenn-Air on and off for a variety of wind conditions. Four pressure differences were monitored:

- From the 4-way averaging exterior tap to the vicinity of the Jenn-Air;
- From the 4-way averaging exterior tap to the vicinity of the furnace;
- From the vicinity of the Jenn-Air to a tap mounted on the outside wall close to the Jenn-Air exhaust;
- Across the Jenn-Air fan, to give an indication of flow rate.

5. RESULTS OF THE TESTS

5.1 Fan characteristics

The fan characteristics are presented in figures 4 to 7. The flow rates are corrected to standard conditions of 101.325 kPa, 21 C and 0% R.H. The estimated error is 5 L/s over the range 20 L/s to 350 L/s. A discrepancy was later discovered in one of the manometers used for this test, and the pressure data may accordingly have a systematic error of 4.5%.

5.2 Direct measurements of fan depressurization

The results of the single-appliance are tests presented in Tables 1 to 5. The first four tables refer to the operation of the Jenn-Air fan under four different configurations. These configurations differ only marginally, and their effects are probably swamped by variations in wind conditions from one test to another. Throughout the four tests the wind direction was generally from the east to north-east (a wind from the east is denoted as 90° in the nomenclature used in this report) and the Jenn-Air outlet was therefore on the leeward side of the house. Comparing tables 3 and 4, the only difference in configuration was the opening or closing of the furnace room door, and the meteorological conditions are almost identical in the two tests. The difference in comparative results from the two tests is small, and within the magnitude of experimental error. The effect of opening and closing the furnace room door can therefore be described as trivial.

On all four tests the depressurizing effect of the Jenn-Air was identical at the two measuring points - near the appliance and near the furnace - within the range of experimental error and resolution. Averaged depressurizations range from 4.1 Pa to 5.6 Pa.

Table 5 gives the results for the Air King range hood. The average depressurization is the same at the two locations, and is 3.2 Pa. It should be noted that this two-fan unit has an unstable pressure-flow characteristic that was evident both when measuring the characteristic and when conducting these depressurization tests.

For experimental convenience, the single-appliance tests on the dryer were conducted as part of the combined-appliance tests. It was decided to ignore the range hood in these tests, and concentrate on the combination of dryer and Jenn-Air. The results are presented in tables 6 to 9. These cover four combinations: furnace door open or closed, and dryer operating with hot or cold exhaust. For practical purposes these can be considered as replications of the same test, with minor changes in

configuration and with wind effect as possibly the main variable, though wind speeds were moderate for most of the test.

The averaged depressurization of the Jenn-Air (alone) ranged from 4.8 Pa. to 5.7 Pa. The averaged depressurization of the dryer (alone) ranged from 1.2 Pa to 2.1 Pa . The averaged depressurization of the two appliances, operating together, ranged from 7.4 Pa to 8.6 Pa.

These figures clearly show that the depressurization effects of individual appliances cannot be combined by simple addition.* The obvious explanation is that each appliance modifies the operational characteristic of the other. It was postulated that each appliance would cause an increase in the pressure drop across the other, and a simple experiment was set up to test this.

The pressure drops across the dryer and Jenn-Air were measured with the appliances operating singly and in combination. Two runs were conducted at each configuration. The results are presented in table 10. It will be noted that the dryer causes an increased pressure drop at the Jenn-Air, ranging from 0.5 to 1.0 Pa. Similarly, the Jenn-Air causes an increased pressure drop across the dryer, ranging from 3 to 5 Pa. The effect of the dryer on the Jenn-Air is within the range of experimental error and cannot be viewed as a convincing result. But the effect of the Jenn-Air on the dryer is quite large, and significant.

Thus, it can be assumed that, with this particular combination of appliances, the non-additivity of depressurization effects is due to the shift of the dryer operating conditions induced by the Jenn-Air.

CMHC and the Consortium have discussed this finding, and have rightly pointed out that flow rate is the controlling variable when dealing with combined fan operation in a computer model. Taking the data from table 10 and applying them to the fan characteristics in figures 4 and 6, it will be seen that the combined flow of the two fans is approximately 130 L/s (using the hot dryer fan characteristic in figure 6). An interactional shift of 5 Pa on the dryer characteristic, as revealed in table 10, produces an equivalent shift of about 2 L/s in the flow rate through the dryer. This corresponds to less than 2% of the combined flow of the two fans, and from the point of view of computer modelling can be considered trivial.

5.3 Pressurizing around the furnace at start-up

The main results are presented in Table 11. It will be observed that, in general, the Torin elevates the pressure around the furnace by typically 3 to 4.5 Pa. There is one freak elevation of 0.5 Pa which is possibly due to wind effect.

It needs to be emphasized that the pressure data in this table consist of actual pressure differences, not changes from the background condition as used in tables 1 to 9. The data in table 11 are therefore not

*Note: Part of the explanation for this is that the level of house depressurization is also influenced by the house building envelope flow/pressure characteristic, which is non-linear. Thus SRC's following explanation, while not incorrect, is incomplete in that it does not address this side of the issue.
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inconsistent with the data in tables 1 to 9, though there appear to be wind effects at work, of about 2 Pa magnitude.

Concentrating on the first test sequence, which seems to have greater consistency, it will be noted that the Torin fan can overcome the effects of a no-fan situation and will actually produce a positive pressure drop between the furnace and outside. When the dryer is operating, the Torin approximately cancels the depressurizing effect of the dryer.

With the Jenn-Air, operating alone or in combination with the dryer, the Torin is incapable of counteracting the depressurizing effect and there is still a significant residual depressurization around the furnace. With the Jenn-Air and dryer combination this residual effect may be large enough to cause concern - particularly in a more airtight house, where the pressure effects will be amplified.

These findings should not be interpreted as a general condemnation of this remedial method. The findings are specific to the Torin fan which, with reference to figures 4 and 7, is seen to have a much lower flow capacity than the Jenn-Air. If a duplicate Jenn-Air fan had been used for remedial pressurization, it is highly probable that it would have given the required counteracting effect.

5.4 Airtightness tests

The main parameters of the airtightness test are presented in table 12. The test numbers are not given in sequence but are grouped according to the test configurations. The experimental points and the fitted curves are shown in figures 8 to 12. The intention here is merely to give some visual indication of experimental scatter, and the tests are grouped in sequence, often with no strong relation between curves on the same graph.

Attention is drawn to tests 20, 23 and 26, which are repeats at the normal condition for airtightness tests. There is good agreement between 20 and 23, but 26 shows a significant difference. This is deceptive however; in figure 11 the curves for tests 23 and 26 are almost coincident. From earlier studies at SRC it has been established that, for a typical Saskatchewan house, C is typically 25.5 L/s/Pa^n , n is typically 0.763, and ELA at 10 Pa is typically 0.055 m^2 . The test house parameters fall close to these typical values, with the implication that the house has an ordinary level of airtightness. Thus, computer modelling may be required to extrapolate the findings of this study to houses of higher-than-ordinary levels of airtightness.

Tests 14A and 27A are identical with tests 14 and 27, but the analysis has been conducted differently. The objective was to investigate Timusk's method (reported previously) of deducing exhaust appliance characteristics from the difference of two airtightness test runs - one with the exhaust appliance off, and one with it on. The test data of 14A

and 27A use absolute pressure differences, namely without subtraction of the background pressure difference. Instead of blower door flow rates, the combined flow through the Jenn-Air and dryer was used for 14A, and the flow through the Torin was used for 27A. These flows were determined by measuring the pressure difference across the fans, and using this to pick off the flow on the appropriate fan characteristic. Thus 14A and 27A consist of the real appliance characteristics. A check against Timusk's method shows good agreement in one case and some 20% disagreement in the other. The results of this calculation are not reproduced here; it is presumably something that the Consortium would wish to check for itself.

Table 13 was obtained as part of Test 29, and shows two comparative pressure differences obtained during the airtightness test. The first is the normal interior-exterior pressure difference, the second is the pressure difference through the house ceiling. It is included here for interest's sake only.

5.5 Tests with remedial inlet air supply

The results for the Jenn-Air and Kenmore air supply are presented in tables 14 and 15 respectively.

Referring to table 14, comparisons with the Jenn-Air "on" and the air supply respectively open and blocked show only a marginal change in the pressure effects. It follows that the remedial air supply has only a trivial effect on house depressurization, and certainly is not capable of counteracting the effect of the Jenn-Air. This applies no matter whether the air supply is ducted or delivered through an open port in the house envelope - though in the latter case the remedial effect is slightly more pronounced.

Referring to table 15, the tests with the dryer "on" display no significant change in depressurization when the air supply status is changed from open to blocked. Once again, the air supply obviously has no significant effect. But in this case, bearing in mind the low pressure effects established by the dryer fan, it is doubtful that a remedial air supply would be needed at all.

With the benefit of hindsight these findings are not surprising; the depressurization effects of an exhaust fan will be cancelled only by an approximately similar rate of inlet flow. It will require practically as much pressure drop to deliver this inlet flow as it does to deliver the exhaust flow. The pressure drop established in the exhaust ducting by the exhaust fan is typically 150 Pa. The pressure drop in the inlet ducting is determined mainly by house depressurization effects and is of the order of 5 Pa. Clearly, for proper balancing of an exhaust appliance, the air inlet system must have approximately the same configuration as the exhaust, with regard to the sizing of fan and duct.

The measurement of thermal comfort parameters is based on the work of Fanger (1) and Olesen (2). The latter reference provides the theoretical basis for the operation of the Bruel & Kjaer thermal comfort meter, and should be consulted for an explanation of the thermal comfort parameters.

Table 14 shows some marginal changes in thermal comfort (Percent People Dissatisfied) around the Jenn-Air. Table 15 shows a significant reduction in thermal comfort level whenever the air inlet is open. The prevailing low temperature in the basement means that thermal comfort levels are generally low, as shown by the high values of PPD.

In assessing the importance of these thermal comfort measurements two factors must be borne in mind: first, the temperature of the incoming cold air was 3 C, which is far higher than normal winter values; secondly, though the inlet flow rate was not measured it can be assumed to have been very small by virtue of the arguments given above. Thus, although the thermal comfort measurements are of interest, they relate to a temperature situation that is not typical, and to a remedial air inlet system that is ineffective. Given a fan-driven inlet air supply, and outside temperatures of around -20 C, the effect on thermal comfort would probably be large enough to cause concern about localized remedial air supplies.

5.6 Investigation of wind effect

The results are presented in tables 16 to 20, which cover five test series under different wind conditions. Three types of pressure difference are tabulated:

- Difference between kitchen and single tapping on the south wall;
- Difference between kitchen and four-way averaging tap outside;
- Difference between basement and four-way averaging tap outside.

For each of these configurations two types of pressure difference are presented: the first is the background pressure difference with the Jenn-Air off; the second is the change in pressure difference caused by the Jenn-Air operation.

For each test the wind data have been treated to give the wind vectors normal to the east and south walls - taken as positive when the vector faces into the wall.

The results are plotted in figure 13. The data in the top graph (13a) show much greater scatter than in the two graphs below. This is ascribed to the effect of the single pressure tapping on the south wall, which will be much more sensitive to slight changes in the wind.

Graphs 13b and 13c are based on the use of the four-way averaging system outside the house. This is less sensitive to wind changes, as evidenced by the relatively low scatter. The data from test series four (table 19)

consistently show freak behaviour on the two lower graphs. If these data are ignored, the consistency is much improved and there are clear trends in the data - represented by the broken lines in the graphs.

The pressure changes created in the kitchen by Jenn-Air operation (13b) are essentially independent of wind conditions. In the basement (13c) there is an apparent trend, though this falls well within the range of experimental error and can be considered trivial. In total, it can be concluded that wind has no significant effect on the depressurization caused by the Jenn-Air.

The background pressure differences show variations within the range of experimental error and are essentially insensitive to wind effect, though there does appear to be a slight trend in graph 13c.

6. DISCUSSION OF THE REQUIRED SYSTEM OF CONTROL

Although the foregoing findings are generally negative, they point clearly to a potentially workable solution of the depressurization problem. The specifics of this solution are reviewed in this section.

6.1 Mechanical considerations

First of all, it is fairly certain that an inlet air supply, driven by a Jenn-Air fan (or one with similar characteristics), would overcome most of the depressurization effects around the furnace. Furthermore, since this would set up an almost balanced condition between air inlet and appliance exhaust, it is likely that this remedy would have almost equal validity in leaky houses or relatively airtight houses.

Secondly, it has been established that the location of fans is not important, since depressurization effects are propagated throughout the house almost uniformly. Thus, a remedial air supply with its own Jenn-Air fan can be located anywhere in the house with equal effect.

This leads to the question: is it better to install the remedial air supply close to the Jenn-Air appliance or close to the furnace? In answering this question, thermal comfort must be a prime consideration. Serious thermal comfort problems have not been demonstrated in this study, mainly because the test conditions were inappropriate. But, with the kind of remedial air supply that is now being proposed, it can be assumed that such problems will occur. Thermal comfort effects will be less obtrusive if the remedial air supply is ducted close to the furnace, therefore this is the preferred location.

One final question remains: how should the remedial air supply fan be controlled?

6.2 Control considerations

There are two obvious options:

- The fan can be switched on for about one minute at the time of furnace start-up.
- The fan can be switched on whenever the Jenn-Air, or any major exhaust appliance, is operative.

The first option is relatively simple and inexpensive, since the fan is close to the furnace and there is no great difficulty in coupling to the furnace control system. This has an obvious disadvantage, particularly

in airtight houses: it does not solve the problem of ventilation air supply when a major exhaust appliance is being used.

The second option may involve lengthy runs of control cable from the exhaust appliance to the remedial air fan, and in many houses with finished basements this may be messy, difficult and costly. However, this option has the advantage of tackling the problem at its source, namely, it counteracts depressurization effects only when these effects are present. Thus, it is simultaneously a safeguard against backdrafting and an effective ventilation measure.

Each option has its advantages and disadvantages, and it may therefore be advisable to adopt two different strategies, depending on the airtightness of the house. For relatively leaky houses the first option would be preferable. For relatively airtight houses the second option would be preferable. If a single strategy were to be adopted for the entire housing stock, the second option would be the obvious choice, since it protects against most eventualities. These are things that the Consortium will have to decide.

6.3 Code and regulatory factors

Gas furnace installations in all provinces fall under the jurisdiction of the National Standard CAN1-B149.1-78 (reference 3). In section 3.1.1 of this Standard it states:

"Appliances, accessories, components, equipment and materials used in installations shall be of a type and rating approved for the specific purpose for which they are employed and acceptable to the enforcing authorities."

The enforcing authorities are differently constituted in the various provinces, and interpret the above requirement in various ways. Thus, in Ontario and several other provinces, the enforcing authorities are fairly flexible on such things as retrofitted flue dampers, but less flexible on any modification of the furnace unit itself.

In Saskatchewan, the relevant authority is the Gas Inspection Branch of the Department of Labour - a provincial body. This authority is rather strict on modifications to either the flue or the furnace. However, it is fairly tolerant of modifications to the house thermostat control system.

(A case in point is the Automatic Fresh Air Control system now being manufactured by Hoyme Manufacturing Ltd.(4), which is activated by the house thermostat control system where it couples into the furnace, and opens a fresh air vent close to the furnace throughout the burn period. The information on this product was made available to SRC in April, after this project was concluded. Its value as a

remedial air supply device should perhaps be tested independently, though it is fairly certain what the findings will show.)

The Gas Inspection Branch in Saskatchewan has confirmed that it has no serious objections to devices which involve modification to the thermostatic control system, though this should not be seen as a blanket approval. In the above quotation from the National Standard, the important wording is "of a type and rating approved for the specific purpose for which they are employed". Essentially, this means that the equipment must be tested and certified for its proposed use - probably by the Canadian Gas Association - before it can be considered for approval in the individual provinces. The file on the Hoyme device (mentioned above and submitted under separate cover) shows the various stages that must be gone through to secure certification and provincial approval.

Further to this, it is the authors' understanding that, if a device has received certification and provincial approval, then it will not invalidate any existing warranty on the furnace, and neither will it invalidate any existing fire insurance on the house in the event of a claim. However, it should be noted that the above interpretation of these issues may not apply in all cases; it will probably depend on the fine print written into the individual warranties and insurance agreements.

The main conclusions arising from this discussion are as follows:

- In principle, there would appear to be no objection to the use of a remedial air supply device which is activated by the house thermostat system and is coupled into this system at the furnace - provided that it has received certification by the Canadian Gas Association, and provided that it has been approved by the enforcing authorities in each of the provinces in which it is to be used.
- In general, a device meeting these requirements should not encounter problems with loss of furnace warranty or loss of fire insurance coverage, though this would need to be established on a case-by-case basis.

Assuming that such a system of control is developed and marketed, the following design considerations should be taken into account:

- The control should be connected across the step-down transformer which powers the house thermostat system, and it must be connected in parallel so that it does not affect the operation of the thermostat and its anticipator system.
- The control device should not significantly increase the current loading on the step-down transformer, otherwise it could cause either failure of the transformer or transient spikes which might impair the operation of solid-state thermostat systems.

- The system which recommends itself is a timer-relay with a 2,000 ohm coil, a built-in timer which can be set to de-activate the relay after one-to-two minutes, and relay switching points which are rated for the current that will be required by the remedial fan. It is understood that such devices are available.

6.4 Dealing with fireplaces

At the request of the Consortium some consideration is now given to the special control problems presented by fireplaces. When a fireplace is operating, its physical environment is changed in many ways. At least four of these physical changes can be applied individually to methods of control:

- The local temperature increases fairly rapidly. A temperature-sensing switch, located close to the fire, could therefore be used to activate the pressurization fan. The most suitable switch would appear to be the helical bi-metallic strip system, as used in most (probably all) FAN-LIMIT switches on natural gas furnaces. The device is inexpensive (around \$30). It is robust and comes equipped with relay switches that have enough current-handling capability for direct connection to the pressurization fan. The only foreseeable problem concerns the mounting of the switch: it must be mounted with the temperature-sensing element exposed to high temperature, and the relay system in a relatively low ambient temperature. These switches come with various "reaches" of sensing element. A long-reach element would allow the required isolation of the relays from high ambient temperature conditions.
- An active fire emits radiation across a wide part of the electromagnetic spectrum. This suggests that infra-red emission could be used as the basis for control. A wide range of security alarm and fire safety systems operate on this basis and might be adaptable to the required system of control, though the cost would be much higher than that of the fan-limit switch mentioned above.
- When a fire is started it is necessary to open the flue damper (if fitted). Dampers could be provided with some kind of interlock that automatically activates the pressurization fan or alerts the operator to the need to switch on the fan.
- An active fire causes a depressurization of the house. This is not only the source of the problem being considered in this study; it is also a measurable quantity that can be used as a basis for control. This method of control has wider possibilities that are considered in the following section.

6.5 A pressure-based control system

Viewing the house in a general way, it must be recognized that the house could contain any number of exhaust systems which can operate individually or in multiple combinations. The effect of these on the combustion appliances will vary from house to house, depending on variations in airtightness. Thus, in an airtight house, a single exhaust appliance (including the fireplace) may be sufficient to cause backdraft of a furnace flue. Conversely, in a leaky house, the simultaneous operation of several exhaust appliances may not be enough to cause flue backdraft.

So far in this study we have tended to consider each appliance in isolation, and have looked at methods of control based mainly on yes-no systems - namely, on whether the problem-causing appliance is operating or not. This has led us to consider individual control systems operating off each appliance and coming together to control the pressurization fan. This approach might be justifiable when there is only one exhaust appliance to be considered, but it can become very complicated when there are several appliances.

Also, consider how one might phrase a Standard on the required systems of control - bearing in mind that the level of airtightness of the house, and the various combinations of systems, are factors that must be taken into account.

A pressure-based control system avoids these problems. It responds to the critical variable and is totally independent of the cause of depressurization. Also, from earlier findings in this study, its operation would be independent of the locations of the pressure-sensing device and the various depressurization systems. The logic of such a system is most appealing.

Basically, the system would operate as follows: a pressure-sensing device, monitoring the pressure between two fixed points, would activate the pressurization fan when the pressure difference reached a pre-set critical value. There are three primary elements in this design: the value of the pre-set level and the location of the two fixed points:

- The first fixed point would obviously be close to the dilution device of the furnace.
- The second fixed point would have to be essentially external to the house. A four-way averaging system would suffice (figure 13 shows that wind effects reduce to pressure difference variations of about 1 Pa), but would be unnecessarily complicated and prone to tampering. A single exterior tapping, mounted in the attic cavity, would make use of the attic's (presumed) ability to smooth-out wind effects. This would be simpler to install, and less prone to failure. An even better way would be to tap the pressure at the

point that really matters, namely inside the flue and close to the top. A small-diameter metal tube (3 to 6 mm) could easily be inserted in the flue, with a static pressure tap near the top. This would have to receive the approval of the gas inspection authorities in each province, but the modification is small and a strong case could be made for its approval.

- The pre-set level would vary according to installation (eg. interior/exterior location of flue, height of flue, etc.). FLUESIM should be able to establish a simple set of rules.

Within the constraints of this study it has not been possible to survey the market for the most appropriate pressure-sensing device, but it is believed that such devices exist, or can be made to do the job with some modification. Cost is the only unresolved factor at this point.

Obviously, more is needed than a simple pre-settable differential pressure switch. Such a switch would activate the pressurization fan, which would then pressurize the house, deactivate the pressure switch and thus switch itself off. This control system would therefore be inherently unstable. The simplest remedy is to include a self-latching relay with a deactivation delay of about ten minutes. Thus, when the pressure switch activates the fan, the relay will activate and will ensure that the fan operates for ten minutes before returning control to the pressure switch. Such a system, and its operational modes, will require a moderate amount of product search, research and development.

7. CONCLUSIONS

The first conclusion is that the pressure effects of the various fans appear to be transmitted throughout the house fairly uniformly, with no significant attenuation. There are two qualifications to this conclusion: first, the tests were conducted in the absence of any effects from the furnace air circulation fan; secondly, all interior doors were removed, thereby causing a departure from the normal pressure transmission characteristics of the house. Even allowing for these factors, it is possible that the above conclusion would have fairly general application.

The second conclusion is that two fans display interactional effects when operating simultaneously. Thus, their combined performance cannot be obtained by simple addition of their individual performances. The combined flow rates of the two fans differs from the sum of their individual flow rates (operating alone) by less than 2 percent. For the purposes of application and computer analysis this can be considered trivial.

A large series of airtightness tests has been conducted on the house with various combinations of fan usage and vent sealing. These, together with other results, should provide enough information to allow analysis and extrapolation of the results to other houses with different characteristics. However, some caution is advised when conducting such extrapolations. The non-additivity of fan effects, reviewed above, is believed to extend to combinations of exhaust appliances and blower-door fan. Two special analyses (14A and 27A in table 12) have been included to allow the Consortium to check this.

Tests on remedial air supplies, consisting of a simple ducting of outside air (without fan) to the vicinity of the exhaust appliance, have been found unsuccessful. The changes in depressurization produced by this type of air supply are trivial. It is argued that, to counteract the depressurizing effect of an exhaust appliance, the inlet air supply must be provided with a fan similar to that of the appliance.

Thermal comfort measurements were conducted around the Jenn-Air and the dryer, to determine possible reductions in thermal comfort caused by the introduction of remedial outside air. Some reductions in thermal comfort were observed, but these measurements are considered to be of little value since the inlet air temperature was far higher than normal winter values, and the inlet air flow rate was very small. It is believed that major comfort problems would be created with a fanned remedial air supply under typical winter conditions.

A Torin fan has been used to create a pressurization effect around the furnace at start-up. It produced the required effect, but not in sufficient magnitude. The fan was capable of overcoming the effect of the dryer exhaust, but with the Jenn-Air there was enough residual

depressurization to cause concern - perhaps not for the test house, but probably for houses with a higher level of airtightness where the pressurization effects would be amplified.

The partial failure of this remedial technique has been ascribed to the Torin fan itself, which has a flow capacity substantially lower than that of the Jenn-Air. It is argued that, if a Jenn-Air fan had been used for local pressurization, it would have effectively counteracted most of the appliance depressurization effects.

The depressurization performance of the Jenn-Air has been studied under a range of wind conditions, with wind speeds ranging from 12.5 to 37.5 km/h. The data are fairly consistent and show a typical depressurization of about 6 to 7 Pa, with no significant variation in Jenn-Air depressurization over this range of conditions, provided that the exterior pressure is measured using a four-way averaging system. This finding applies to depressurizations in both the kitchen and the basement.

Various methods of pressure control have been investigated and discussed at some length. The main findings are as follows:

- If a house has only one major exhaust appliance, in the form of either a fan system or a fireplace, an electrical control system would be the simplest and least expensive option.
- The control can be based on the operation of the exhaust system (ie. pressurizing fan activated whenever the exhaust system is operational), or on the operation of the furnace (ie. pressurizing fan activated for about one minute at furnace start-up). The former is preferable, since it also serves as a remedial ventilation device.
- For furnace-based control systems the simplest option is to couple into the house thermostat control circuit. The gas inspection authorities would have to approve such a modification and, provided that the device had previously received CGA certification, there should be little difficulty in securing such approval.
- For controls based on fireplace operation, a temperature-operated switch would appear to be the best basis of control, in terms of its advanced level of development, cost and ruggedness.
- For houses with two or more major exhausting appliances, including fireplaces, serious thought should be given to a single method of control using a differential pressure device. This would need some development, but would be most appropriate as a Standard system of control, possibly applicable to oil as well as natural gas furnace systems.

8. REFERENCES

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2. B. W. Olesen, Thermal Comfort, Bruel & Kjaer Technical Review, No.2, 1982, ISSN 0007-2621.
3. Canadian Gas Association, CAN1-B149.1-78, Installation Code for Natural Gas Burning Appliances and Equipment. Published as a National Standard of Canada, 1978.
4. Hoyme Manufacturing Ltd., ACA-PAC Automatic Fresh Air Control, consisting of product specification, and certification and approval documents, C.L. Hoyme Enterprises, Camrose, Alberta, April 1986.

TABLE 1. JENN-AIR OPERATING ALONE

CONFIGURATION:

- Furnace room door open
- Dryer not installed; dryer vent sealed

CONDITIONS:

- Air temperature on main floor 23 C
- Air temperature in basement 20 C
- Outside temperature -3 C
- Wind direction 70°
- Wind speed 10 km/h
- Atmospheric pressure 95.7 kPa
- Jenn-Air pressure difference 160 Pa
- Flow rate derived from charact. 115 L/s

RESULTS:

	<u>Furnace Locn.</u>	<u>Appliance Locn.</u>
Number of items of data:	10	10
Change in press. difference:		
average (Pa)	4.2	4.1
maximum (Pa)	4.5	4.4
minimum (Pa)	4.0	3.8
Standard deviation (Pa)	0.2	0.2

NOTES:

Wind speed was moderately high but the data were consistent. Each of the 10 data items used in statistical analysis consists of an average of 3 to 4 readings.

TABLE 2. JENN-AIR OPERATING ALONE

CONFIGURATION:

- Furnace room door closed
- Dryer not installed; dryer vent sealed

CONDITIONS:

- Air temperature on main floor 22 C
- Air temperature in basement 18 C
- Outside temperature -2 C
- Wind direction 65°
- Wind speed 12 km/h
- Atmospheric pressure 95.7 kPa
- Jenn-Air pressure difference 160 Pa
- Flow rate derived from charact. 115 L/s

RESULTS:

	<u>Furnace Locn.</u>	<u>Appliance Locn.</u>
Number of items of data:	8	7
Change in press. difference:		
average (Pa)	4.5	4.3
maximum (Pa)	4.9	4.8
minimum (Pa)	3.9	3.9
Standard deviation (Pa)	0.4	0.4

NOTES:

0.25 Pa resolution on pressure data.

TABLE 3. JENN-AIR OPERATING ALONE

CONFIGURATION:

- Furnace room door open
- Dryer installed; vent dampered, dryer off.

CONDITIONS:

- Air temperature on main floor 24 C
- Air temperature in basement 20 C
- Outside temperature 0 C
- Wind direction 100°
- Wind speed 3 km/h
- Atmospheric pressure 95.7 kPa
- Jenn-Air pressure diff. 164 Pa
- Flow rate derived from fan charact. 110 L/s

RESULTS:

	<u>Furnace Locn.</u>	<u>Appliance Locn.</u>
Background pressure difference (Pa)	1.6	1.4
Standard deviation on background (P)	0.2	0.2
Change in pressure difference:		
average (Pa)	5.5	5.3
maximum (Pa)	6.0	5.8
minimum (Pa)	5.0	4.8
Standard deviation (Pa)	0.2	0.4
Number of items of data:	11	11

NOTES:

1 Pa resolution on data for furnace location; 0.5 Pa resolution on data for appliance location. Data were read to one-half resolution (.25 and .5 Pa) then rounded to 0.1 Pa.

TABLE 4. JENN-AIR OPERATING ALONE

CONFIGURATION:

- Furnace room door closed
- Dryer installed; vent dampered but not sealed; dryer off.

CONDITIONS:

- Air temperature on main floor 23 C
- Air temperature in basement 20 C
- Outside temperature 0 C
- Wind direction 100°
- Wind speed 3 km/h
- Atmospheric pressure 95.7 kPa
- Jenn-Air total pressure head 159 Pa
- Flow rate derived from fan charact. 116 L/s

RESULTS:

	<u>Furnace Locn.</u>	<u>Appliance Locn.</u>
Background pressure difference (Pa)	1.2	1.1
Standard deviation on background (Pa)	0.3	0.2
Change in pressure difference:		
average (Pa)	5.5	5.6
maximum (Pa)	6.0	6.0
minimum (Pa)	5.0	5.0
Standard deviation (Pa)	0.5	0.5
Number of items of data:	5	5

NOTES:

1 Pa resolution on data for furnace location; 0.5 Pa resolution on data for appliance location.

TABLE 5. AIR KING OPERATING ALONE

CONFIGURATION:

- Furnace room door open
- Dryer installed; vent dampered but not sealed; dryer off.

CONDITIONS:

- Air temperature on main floor 25.8 C
- Air temperature in basement 20.5 C
- Outside temperature -0.2 C
- Wind direction 50°
- Wind speed 5 km/h
- Atmospheric pressure 95.7 kPa
- Air King pressure diff. 26-31 Pa
- Flow rate derived from fan charact. 66-74 L/s

RESULTS:

	<u>Furnace Locn.</u>	<u>Appliance Locn.</u>
Background pressure difference (Pa)	1.1	1.3
Standard deviation on background (Pa)	0.2	0.0
Change in pressure difference:		
average (Pa)	3.2	3.2
maximum (Pa)	3.4	3.3
minimum (Pa)	2.9	3.0
Standard deviation (Pa)	0.3	0.2
Number of items of data:	5	5

NOTES:

TABLE 6. COMBINED OPERATION OF JENN-AIR AND DRYER

CONFIGURATION:

- Furnace room door closed
- Dryer operating with cold exhaust.

CONDITIONS:

- Air temperature on main floor 22 C
- Air temperature in basement 18 C
- Outside temperature 0 C
- Wind direction 90°
- Wind speed 5 km/h
- Atmospheric pressure 95.7 kPa
- Jenn-Air pressure diff. 159 Pa (average)
- Derived Jenn-Air flow rate 116 L/s
- Dryer pressure diff. 157 Pa (average)
- Derived dryer flow rate 37.5 L/s

RESULTS:

	<u>Furnace Locn.</u>	<u>Kitchen Locn.</u>
Background pressure difference (Pa)	1.2	1.8
Standard deviation on background (Pa)	0.3	0.6
Change in pressure difference:		
- with Jenn-Air only (Pa)	<u>5.1</u>	<u>5.4</u>
Standard devn.(Pa)	0.2	0.3
Number of points	5	5
- with Dryer only (Pa)	<u>1.6</u>	<u>1.9</u>
Standard devn.(Pa)	0.6	0.7
Number of points	5	5
- with both appliances (Pa)	<u>8.2</u>	<u>8.6</u>
Standard devn.(Pa)	0.3	0.5
Number of points	5	5

NOTES:

TABLE 7. COMBINED OPERATION OF JENN-AIR AND DRYER

CONFIGURATION:

- Furnace room door open
- Dryer operating with cold exhaust.

CONDITIONS:

- Air temperature on main floor	22 C
- Air temperature in basement	18 C
- Outside temperature	0 C
- Wind direction	90°
- Wind speed	5.3 km/h
- Atmospheric pressure	95.7 kPa
- Jenn-Air pressure diff.	159 Pa (average)
- Derived Jenn-Air flow rate	116 L/s
- Dryer pressure diff.	157 Pa (average)
- Derived dryer flow rate	37.5 L/s

RESULTS:

	<u>Furnace Locn.</u>	<u>Kitchen Locn.</u>
Background pressure difference (Pa)	1.7	0.9
Standard deviation on background (Pa)	0.3	0.3
Change in pressure difference:		
- with Jenn-Air only (Pa)	4.8	5.1
Standard devn.(Pa)	0.3	0.6
Number of points	6	6
- with Dryer only (Pa)	1.2	1.4
Standard devn.(Pa)	0.4	0.6
Number of points	6	6
- with both appliances (Pa)	8.4	8.0
Standard devn.(Pa)	0.7	1.4
Number of points	6	6

NOTES:

Wind gusting from 0.6 to 9.2 km/h.

TABLE 8. COMBINED OPERATION OF JENN-AIR AND DRYER

CONFIGURATION:

- Furnace room door open
- Dryer operating with hot exhaust.

CONDITIONS:

- Air temperature on main floor	22 C
- Air temperature in basement	18 C
- Outside temperature	0 C
- Wind direction	90°
- Wind speed	7 km/h
- Atmospheric pressure	95.7 kPa
- Jenn-Air pressure diff.	159 Pa (average)
- Derived Jenn-Air flow rate	116 L/s
- Dryer pressure diff.	120 Pa (average)
- Derived dryer flow rate	30 L/s

RESULTS:

	<u>Furnace Locn.</u>	<u>Kitchen Locn.</u>
Background pressure difference (Pa)	0.9	0.8
Standard deviation on background (Pa)	0.3	0.2
Change in pressure difference:		
- with Jenn-Air only (Pa)	<u>5.0</u>	<u>5.0</u>
Standard devn.(Pa)	0.3	0.2
Number of points	11	11
- with Dryer only (Pa)	<u>1.3</u>	<u>1.3</u>
Standard devn.(Pa)	0.7	0.5
Number of points	11	11
- with both appliances (Pa)	<u>8.1</u>	<u>7.4</u>
Standard devn.(Pa)	0.3	1.0
Number of points	11	11

NOTES:

TABLE 9. COMBINED OPERATION OF JENN-AIR AND DRYER

CONFIGURATION:

- Furnace room door closed
- Dryer operating with hot exhaust.

CONDITIONS:

- Air temperature on main floor 22 C
- Air temperature in basement 18 C
- Outside temperature 0 C
- Wind direction 90°
- Wind speed 7 km/h
- Atmospheric pressure 95.7 kPa
- Jenn-Air pressure diff. 159 Pa (average)
- Derived Jenn-Air flow rate 116 L/s
- Dryer pressure diff. 120 Pa (average)
- Derived dryer flow rate 30 L/s

RESULTS:

	<u>Furnace Locn.</u>	<u>Kitchen Locn.</u>
Background pressure difference (Pa)	0.9	0.7
Standard deviation on background (Pa)	0.2	0.2
Change in pressure difference:		
- with Jenn-Air only (Pa)	<u>5.7</u>	<u>5.4</u>
Standard devn.(Pa)	0.6	1.6
Number of points	13	13
- with Dryer only (Pa)	<u>1.9</u>	<u>2.1</u>
Standard devn.(Pa)	0.5	0.6
Number of points	13	13
- with both appliances (Pa)	<u>8.6</u>	<u>8.3</u>
Standard devn.(Pa)	0.6	0.5
Number of points	13	13

NOTES:

TABLE 10. INVESTIGATION OF INTERACTIONS BETWEEN APPLIANCES

	Press. Diff. across dryer (Pa)	Press. Diff. across J-A (Pa)	Wind speed (km/h)
<u>Test 1:</u>			
Dryer alone	131.4	-	7
Jenn-Air alone	-	165.8	0
Both operating	134.4	166.3	9
Change in pressure diff.	3.0	0.5	
<u>Test 2:</u>			
Dryer alone	132.4	-	7
Jenn-Air alone	-	163.8	5
Both operating	137.4	164.8	14
Change in pressure diff.	5.0	1.0	

TABLE 11 PRESSURIZING EFFECT OF THE TORIN FAN

	<u>Torin off</u>		<u>Torin on</u>		
	Press Diff. (Pa)	Wind Speed (km/h)	Press Diff. (Pa)	Wind Speed (km/h)	Torin Effect (Pa)
<u>First test sequence</u>					
No fans operating	2	7	-2	5	+4
Dryer only	3.5	7	0	5	+3.5
Jenn-Air only	8	0	4	9	+4
Jenn-Air plus dryer	10.5	9	7	10	+3.5
<u>Second test sequence</u>					
No fans operating	1	12	-2	8	+3
Dryer only	3	7	0	6	+3
Jenn-Air only	5.5	5	5	11	+0.5
Jenn-Air plus dryer	10	14	5.5	13	+4.5

Note: Pressure differences are taken to be positive when outside pressure is greater than inside.

TABLE 12. SUMMARY OF MAIN PARAMETERS FROM THE AIRTIGHTNESS TESTS

Test No	Conditions	BPD (Pa)	C (L/s/Pa ⁿ)	n	ELA (m ²)		r
					@ 10 Pa	@ 50 Pa	
15	FC,CD	0.3	42.351	.5918	.0669	.0776	.99229
19	FO,CD	1.5	30.305	.7194	.0638	.0908	.99860
20	CP,FC,CD	1.0	23.890	.7303	.0515	.0746	.99767
23	CP,FC,CD	2.0	23.260	.7349	.0506	.0739	.99983
26	CP,FC,CD	2.0	25.644	.7100	.0528	.0741	.99988
28	CP,FO,TO,CD	2.0	27.743	.7099	.0571	.0801	.99983
29	CP,FO,CD	2.0	24.711	.7226	.0524	.0750	.99964
16	FC,VT	0.5	27.395	.7863	.0673	.1067	.99175
17	FO,VT	0.3	28.512	.7991	.0725	.1174	.99141
21	JT,CP,FC,CD	2.0	31.534	.6790	.0604	.0805	.99979
25	DT,CP,FC,CD	2.0	24.909	.7314	.0538	.0781	.99956
14	J,DC,FC,CD	7.0	4.757	1.2020	.0306	.0948	.99341
18	J,DC,FO,CD	10.0	15.642	.8288	.0426	.0724	.99923
22	J,FC,CP,CD	7.8	8.065	.9762	.0306	.0659	.99632
24	DH,FC,CP,CD	5.5	15.075	.8399	.0418	.0722	.99947
27	T,FO,CP,CD	-1.5	36.654	.6439	.0647	.0816	.99993
14A	See note	N/A	47.151	.6066	.0770	.0914	.99360
27A	See note	N/A	26.481	.7217	.0561	.0802	.99987

Legend:

BPD Background pressure difference, namely with blower door not operating

J - Jenn-Air is on (no symbol when off)

T - Torin fan is operating in furnace pressurization mode (no symbol when off)

DC - Dryer is on, with cold exhaust (no symbol when off)

DH - Dryer is on, with hot exhaust (no symbol when off)

FC - Furnace room door is closed

FO - Furnace room door is open

CP - Furnace chimney is plugged (no symbol when unplugged)

JT - Jenn-Air damper taped open (no symbol means normal damper action)

DT - Dryer damper taped open (no symbol means normal damper action)

VT - All exhaust vents taped open (air inlets and Torin duct are sealed except where otherwise indicated).

CD - All exhaust dampers operating normally, and unsealed

TO - Torin duct left open (no symbol means duct is sealed)

Note: Tests 14A and 27A are the same as tests 14 and 27, but have been analysed differently (see explanation in section 5.4).

TABLE 13. PRESSURE DROP THROUGH CEILING DURING TEST 29

<u>Pressure difference (Pa)</u>	
<u>Interior-exterior</u>	<u>through ceiling</u>
1	-3
3.4	0
5.8	2
13.5	9
19.0	14
27.8	22
36.3	33
49.8	43

TABLE 14. REMEDIAL AIR SUPPLY EFFECTS AT THE JENN-AIR

Condition	Pressure difference (Pa)		Equiv Temp (C)	PMV	PPD
	at Jenn-Air	at furnace			
Jenn-Air on, ducted air open	6	7	22.9	-0.66	14
Jenn-Air off, ducted air open	1	1	22.0	-0.85	19
Jenn-Air on, ducted air blocked	6	6.5	22.2	-0.79	18
Jenn-Air off, ducted air blocked	-	-	22.2	-0.81	19
Jenn-Air off port blocked	0.8	0.5	22.2	-0.77	17
Jenn-Air on, port open.	5.3	5.0	21.6	-0.92	22

Conditions:

Air temperature on main floor	23 C
Air temperature in basement	21 C
Outside temperature	3 C
Wind direction	90°
Wind speed	3 km/h
Atmospheric pressure	95.7 Pa

Comfort parameters:

Clothing level	0.6
Activity level	1.2
Vapour pressure	0.6 kPa
Standing position	
Resulting comfort temperature	25.0 C

TABLE 15. REMEDIAL AIR SUPPLY EFFECTS AT THE CLOTHES DRYER

Condition	Pressure difference (Pa)		Equiv Temp (C)	PMV	PPD
	at Jenn-Air	at furnace			
Dryer off, ducted air open	-	0.7	18.0	-1.4	49
Dryer on, ducted air open	-	2.7	18.0	-1.4	48
Dryer off, ducted air open	-	0.8	18.2	-1.3	45
Dryer on, ducted air blocked	-	2.8	18.5	-1.2	39
Dryer off, ducted air blocked	-	1.0	18.6	-1.2	40

Conditions:

Air temperature on main floor	18.2 C
Air temperature in basement	21 C
Outside temperature	3 C
Wind direction	90°
Wind speed	3 km/h
Atmospheric pressure	95.7 Pa

Comfort parameters:

Clothing level	0.8
Activity level	1.2
Vapour pressure	0.6 kPa
Sitting position	
Resulting comfort temperature	23.7 C

TABLE 16. FIRST TEST SERIES ON WIND EFFECT

	4-way to basement	4-way to kitchen	South wall to kitchen
Background pressure diff. (Pa)	1.1	1.2	2.0
Standard Deviation (Pa)	0.6	0.5	0.6
Number of points	10	10	10
Change in press. diff. with Jenn-Air on:			
Mean (Pa)	6.9	6.1	5.8
Max. (Pa)	8.9	7.8	7.0
Min. (Pa)	5.9	5.1	4.7
Standard Deviation (Pa)	0.9	2.3	0.8
Number of points	10	10	10

Wind data:

Mean wind speed	16.6 km/h
Standard Deviation	2.6 Km/h
Number of measurements	22
Wind direction	252°
Wind vector normal to south wall	-3.5 km/h
Wind vector normal to east wall	-16.2 Km/h

Conditions:

Air temperature on main floor	21 C
Air temperature on basement level	18 C
Outside ambient air temperature	3 C
Pressure difference across Jenn-Air	159 Pa

TABLE 17. SECOND TEST SERIES ON WIND EFFECT

	4-way to basement	4-way to kitchen	South wall to kitchen
Background pressure diff. (Pa)	1.1	2.8	1.0
Standard Deviation (Pa)	0.6	0.9	1.3
Number of points	6	6	6
Change in press. diff. with Jenn-Air on:			
Mean (Pa)	7.2	6.7	9.3
Max. (Pa)	9.5	10.0	8.7
Min. (Pa)	4.5	6.5	3.7
Standard Deviation (Pa)	1.8	1.0	1.4
Number of points	6	6	6

Wind data:

Mean wind speed	37.5 km/h
Standard Deviation	7.0 Km/h
Number of measurements	16
Wind direction	307°
Wind vector normal to south wall	-34.5 km/h
Wind vector normal to east wall	-14.6 Km/h

Conditions:

Air temperature on main floor	18 C
Air temperature on basement level	18 C
Outside ambient air temperature	3 C
Pressure difference across Jenn-Air	163 Pa

TABLE 18. THIRD TEST SERIES ON WIND EFFECT

	4-way to basement	4-way to kitchen	South wall to kitchen
Background pressure diff. (Pa)	3.7	2.7	5.7
Standard Deviation (Pa)	2.9	1.1	0.5
Number of points	3	3	3
Change in press. diff. with Jenn-Air on:			
Mean (Pa)	6.3	6.8	6.6
Max. (Pa)	-	-	-
Min. (Pa)	-	-	-
Standard Deviation (Pa)	1.7	1.5	1.2
Number of points	3	3	3

Wind data:

Mean wind speed	24.0 km/h
Standard Deviation	- Km/h
Number of measurements	-
Wind direction	78°
Wind vector normal to south wall	7.4 km/h
Wind vector normal to east wall	22.8 Km/h

Conditions:

Air temperature on main floor	22 C
Air temperature on basement level	18 C
Outside ambient air temperature	-5 C
Pressure difference across Jenn-Air	164 Pa

TABLE 19. FOURTH TEST SERIES ON WIND EFFECT

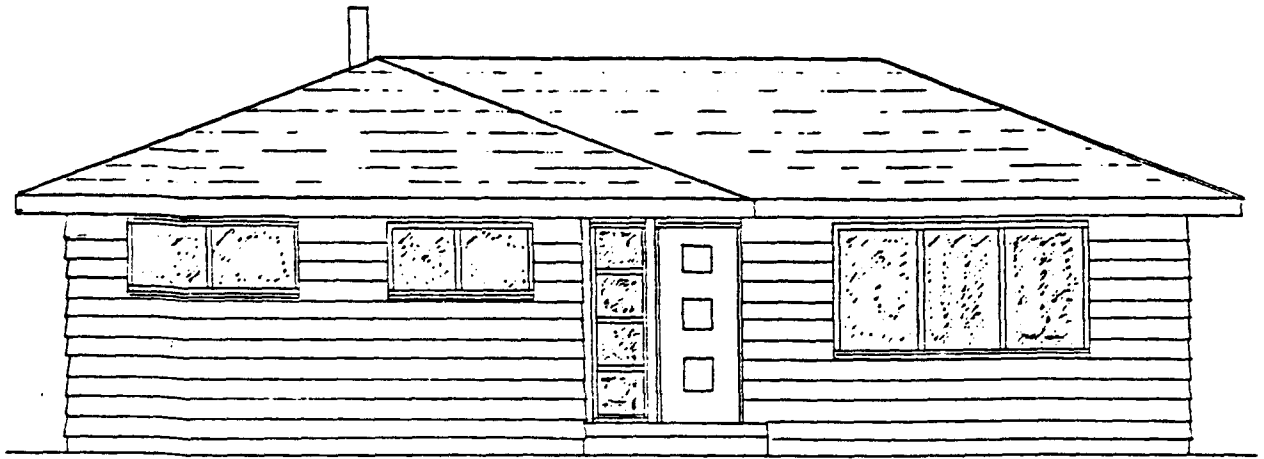
	<u>4-way to basement</u>	<u>4-way to kitchen</u>	<u>South wall to kitchen</u>
Background pressure diff. (Pa)	0.6	0.4	1.8
Standard Deviation (Pa)	0.5	0.7	0.8
Number of points	7	7	7
Change in press. diff. with Jenn-Air on:			
Mean (Pa)	8.3	8.8	7.9
Max. (Pa)	-	-	-
Min. (Pa)	-	-	-
Standard Deviation (Pa)	0.7	0.3	0.7
Number of points	5	4	6

Wind data:

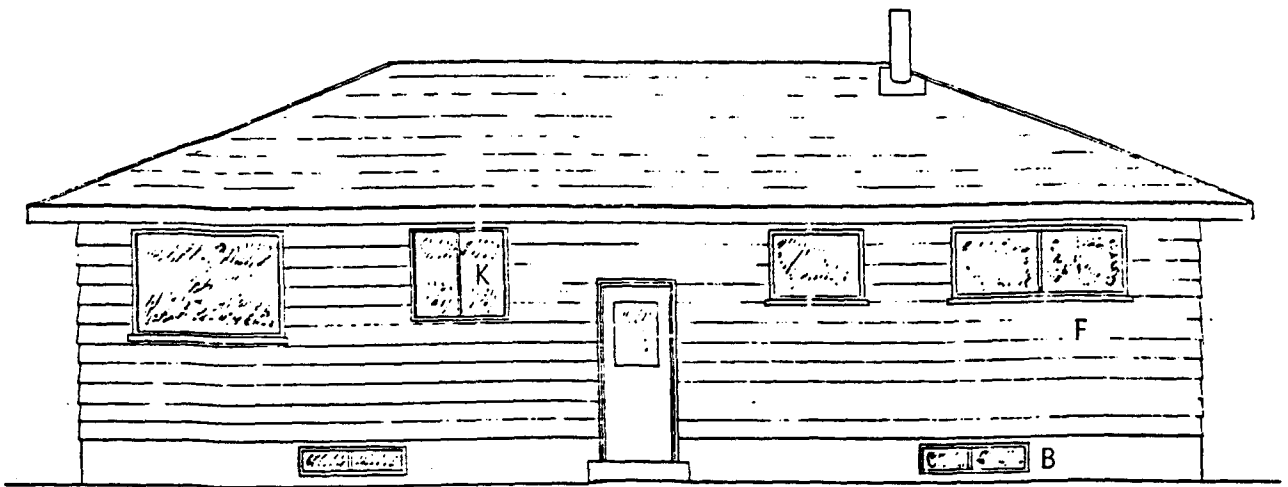
Mean wind speed	21.0 km/h
Standard Deviation	- Km/h
Number of measurements	-
Wind direction	350°
Wind vector normal to south wall	-19.7 km/h
Wind vector normal to east wall	7.2 Km/h

Conditions:

Air temperature on main floor	22 C
Air temperature on basement level	20 C
Outside ambient air temperature	-10 C
Pressure difference across Jenn-Air	157 Pa

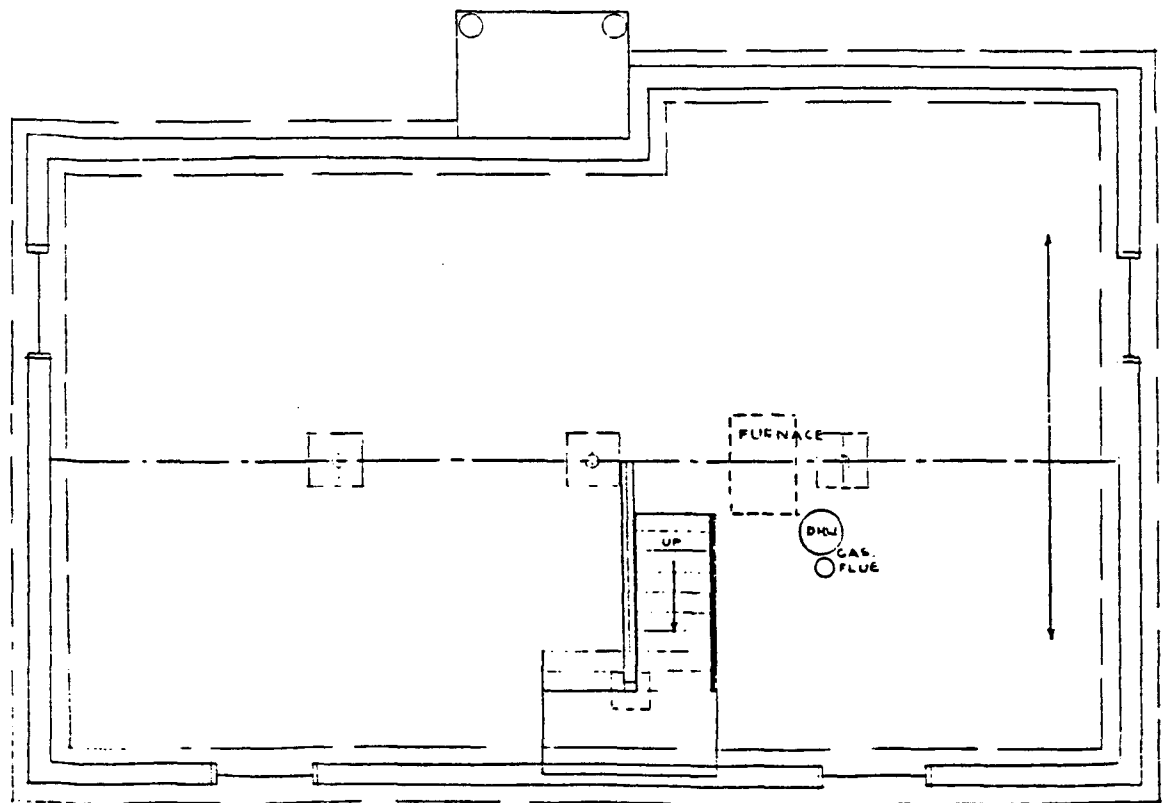
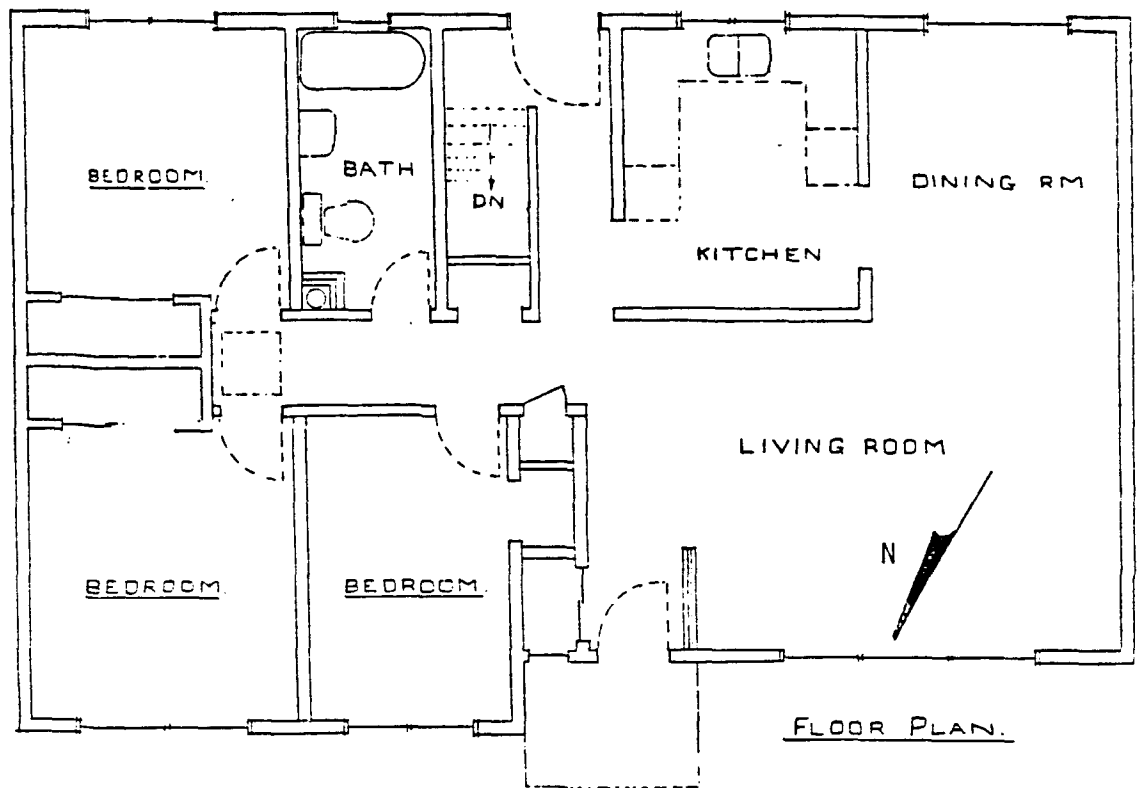


FRONT ELEVATION.



REAR ELEVATION

Fig. 1 House Elevations



BASEMENT PLAN

Fig. 2 House Plans

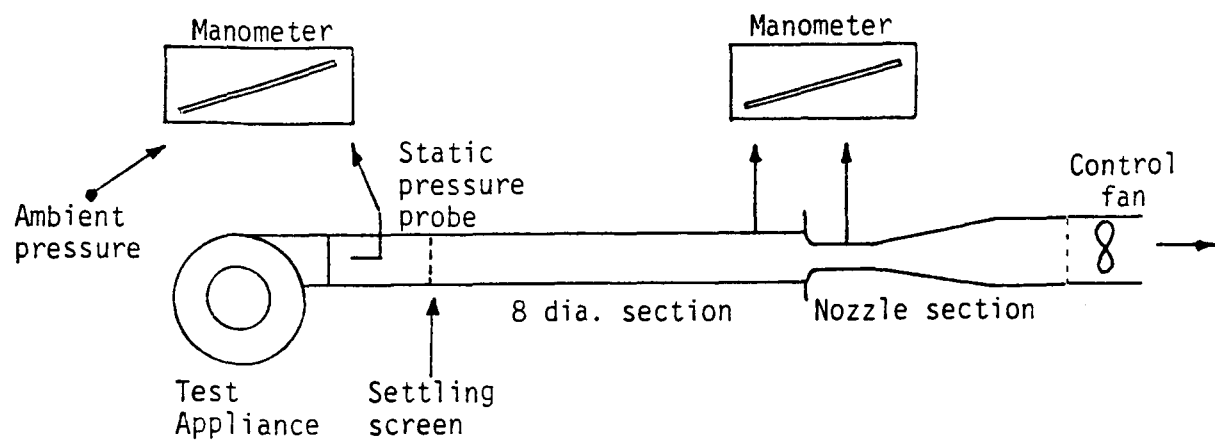


Fig. 3 Test Rig for Measuring Fan Characteristics

JENN-AIR C201

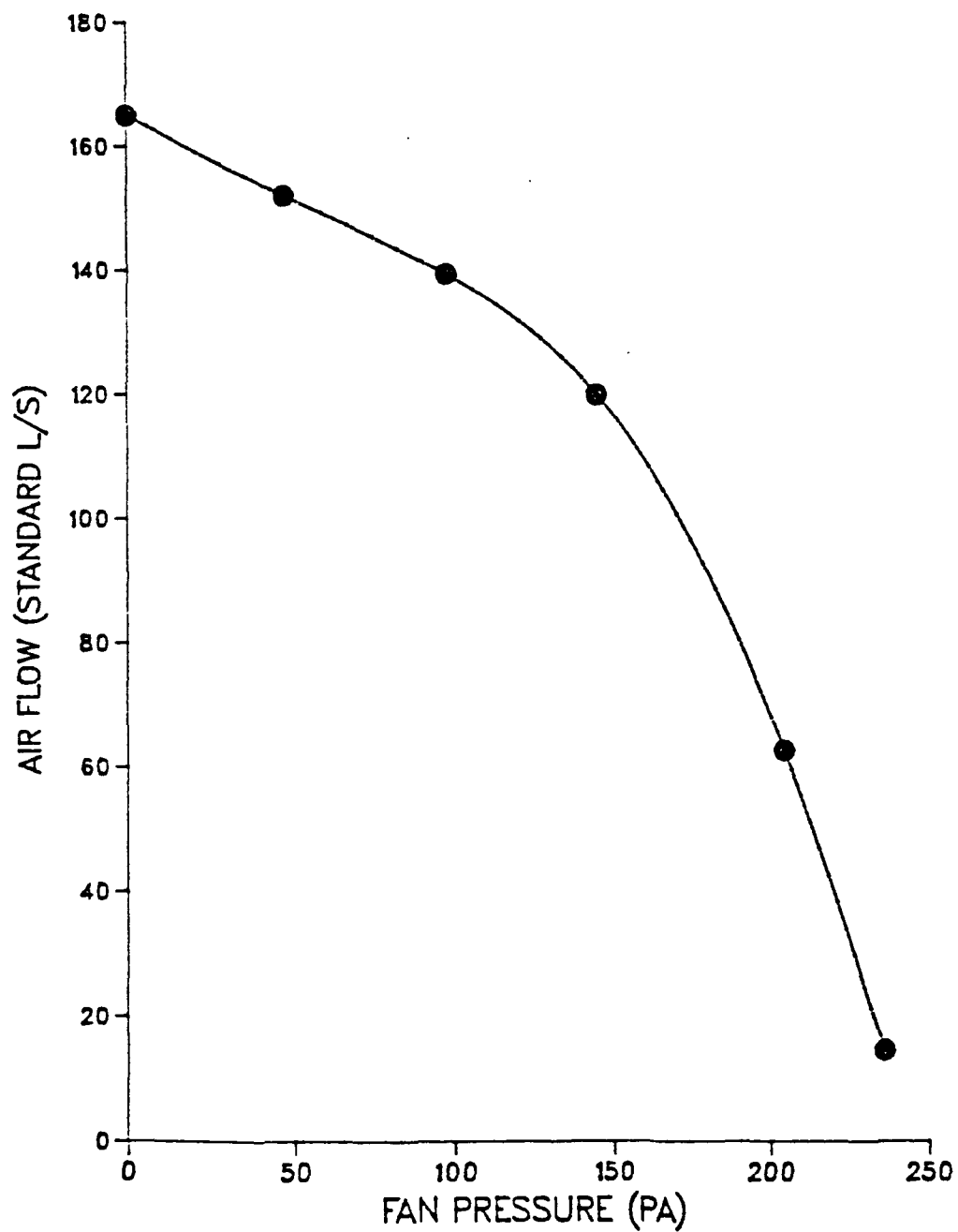


Fig. 4 Jenn-Air Fan Characteristic

AIR-KING 400 SERIES

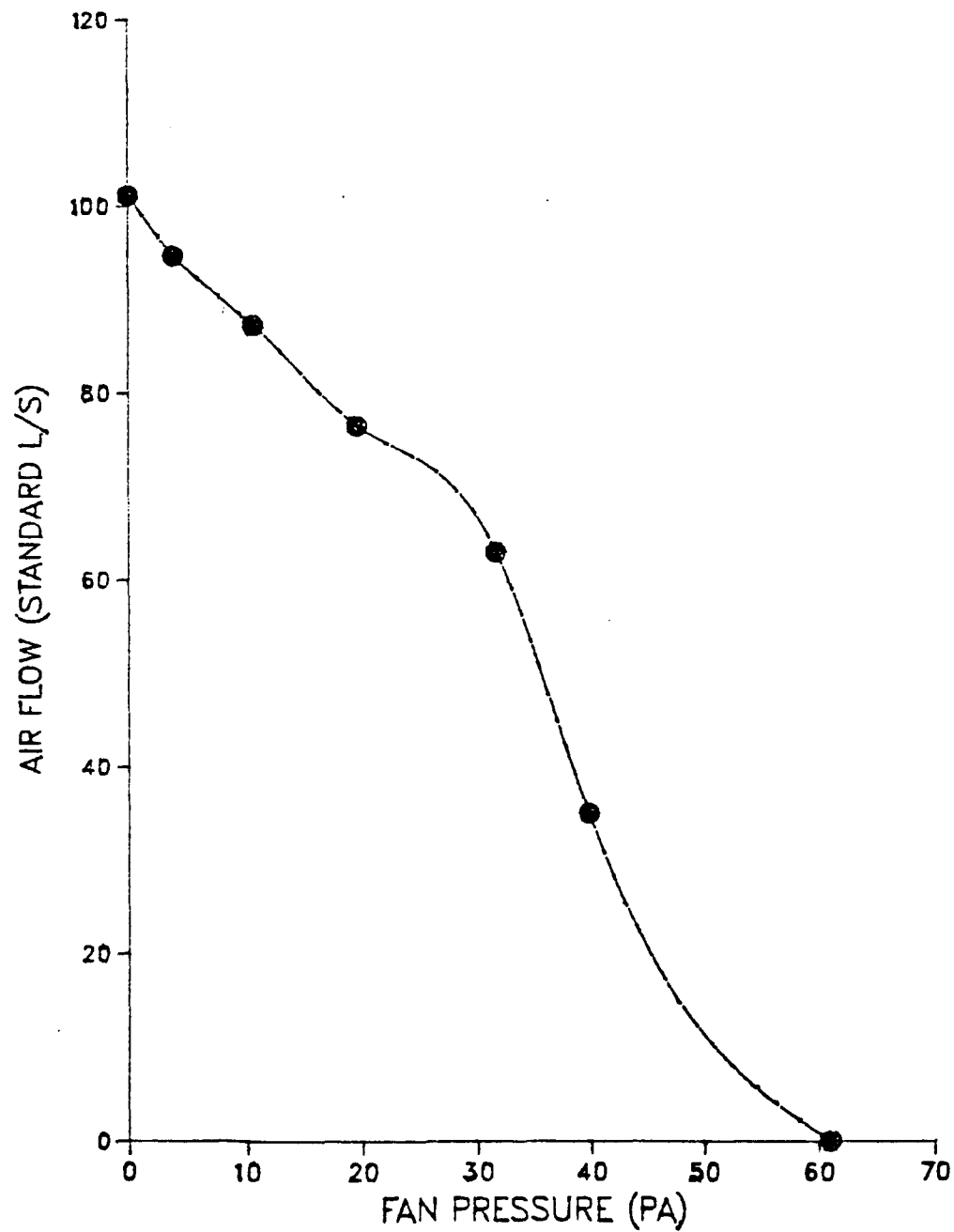


Fig. 5 Air-King Fan Characteristic

KENMORE HD

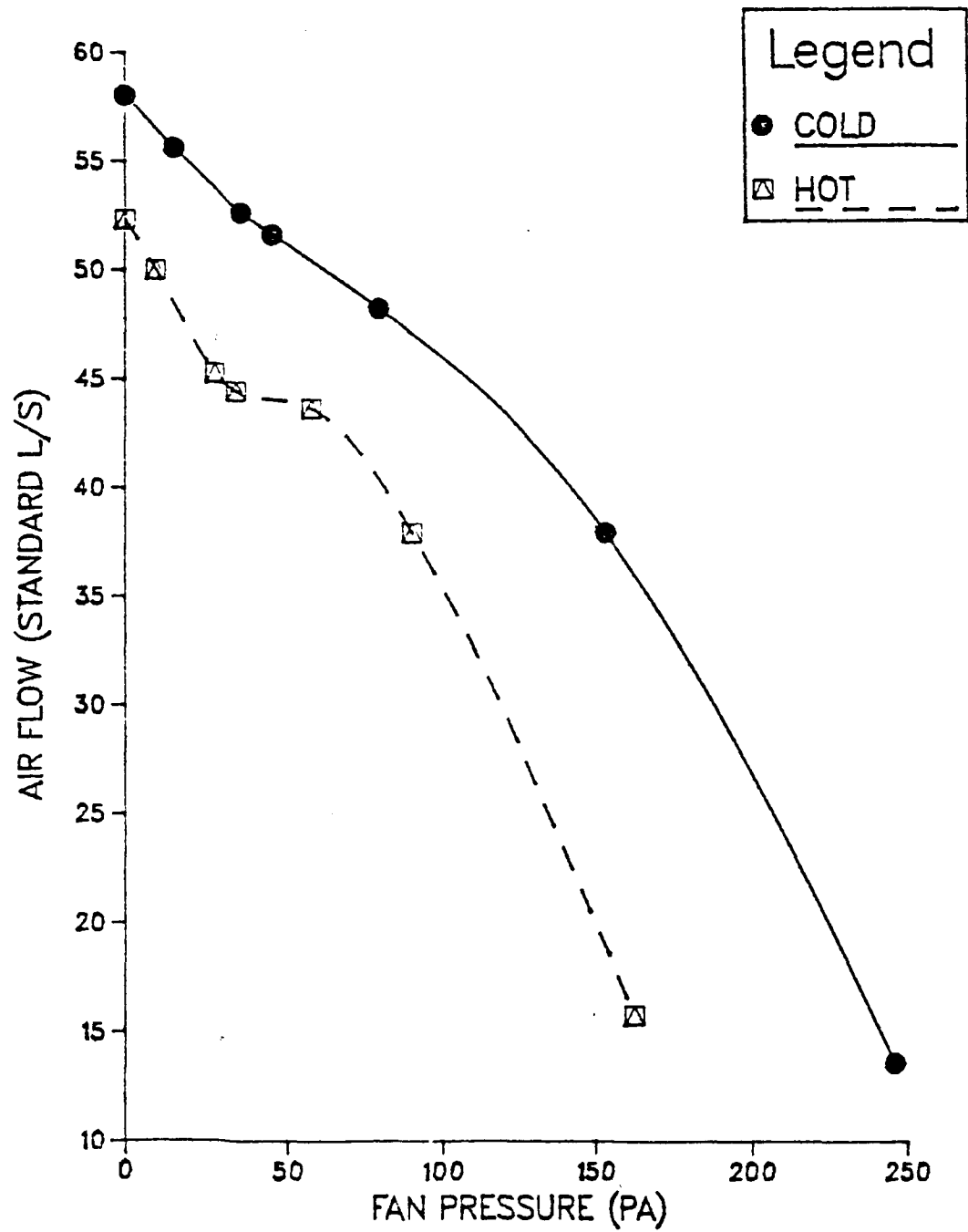


Fig. 6 Kenmore Dryer Fan Characteristic

TORIN GP250

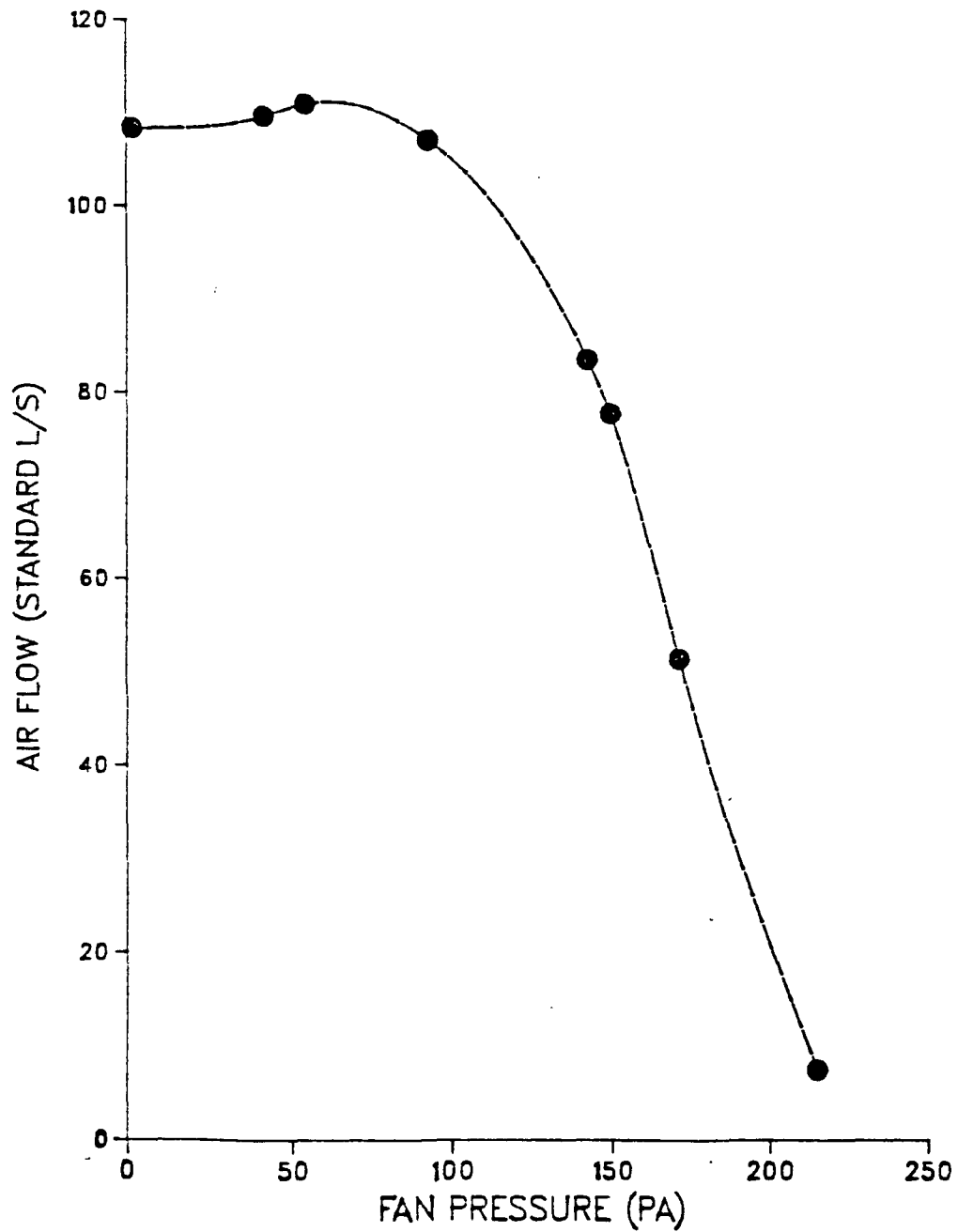


Fig. 7 Torin Fan Characteristic

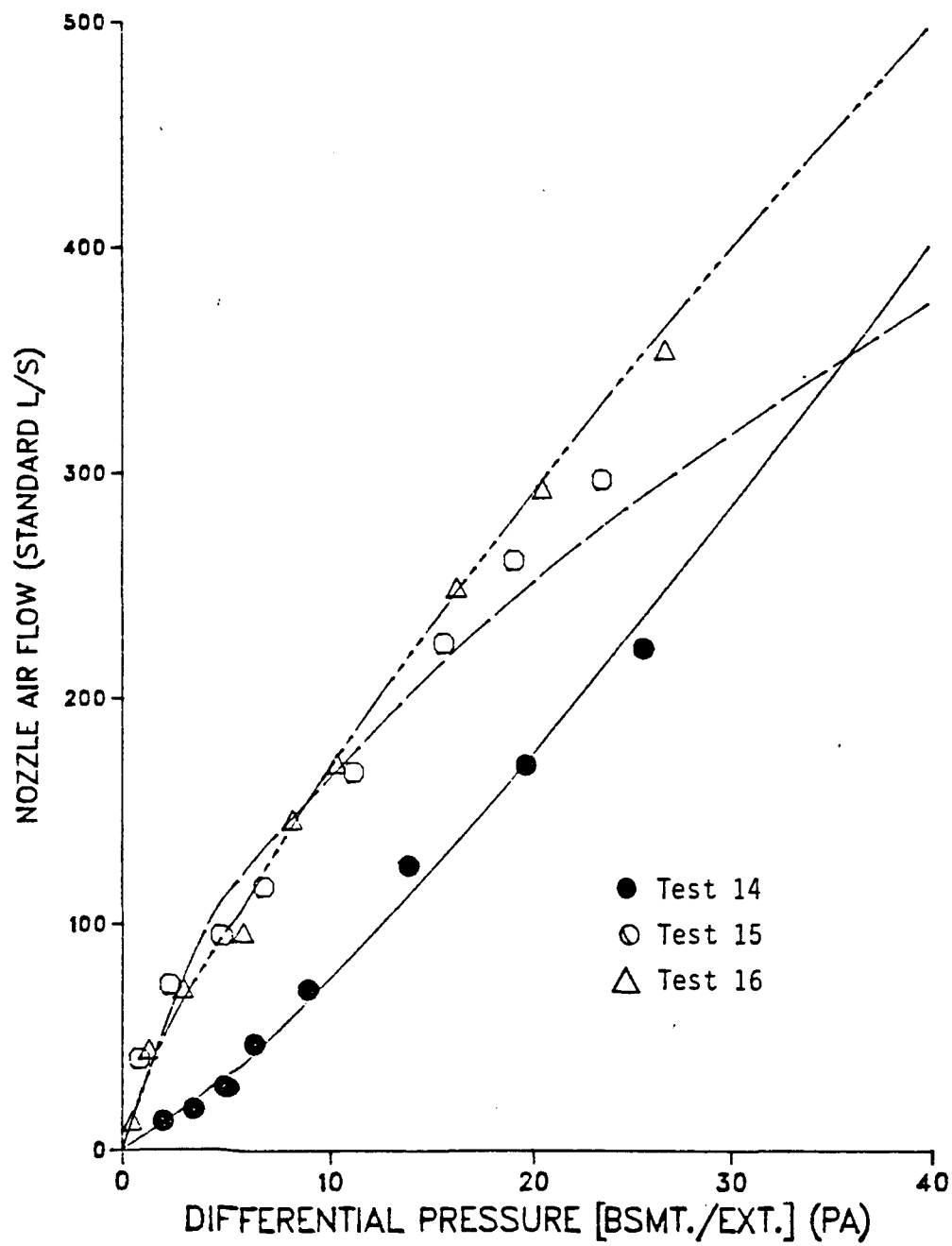


Fig. 8 Tests 14 to 16

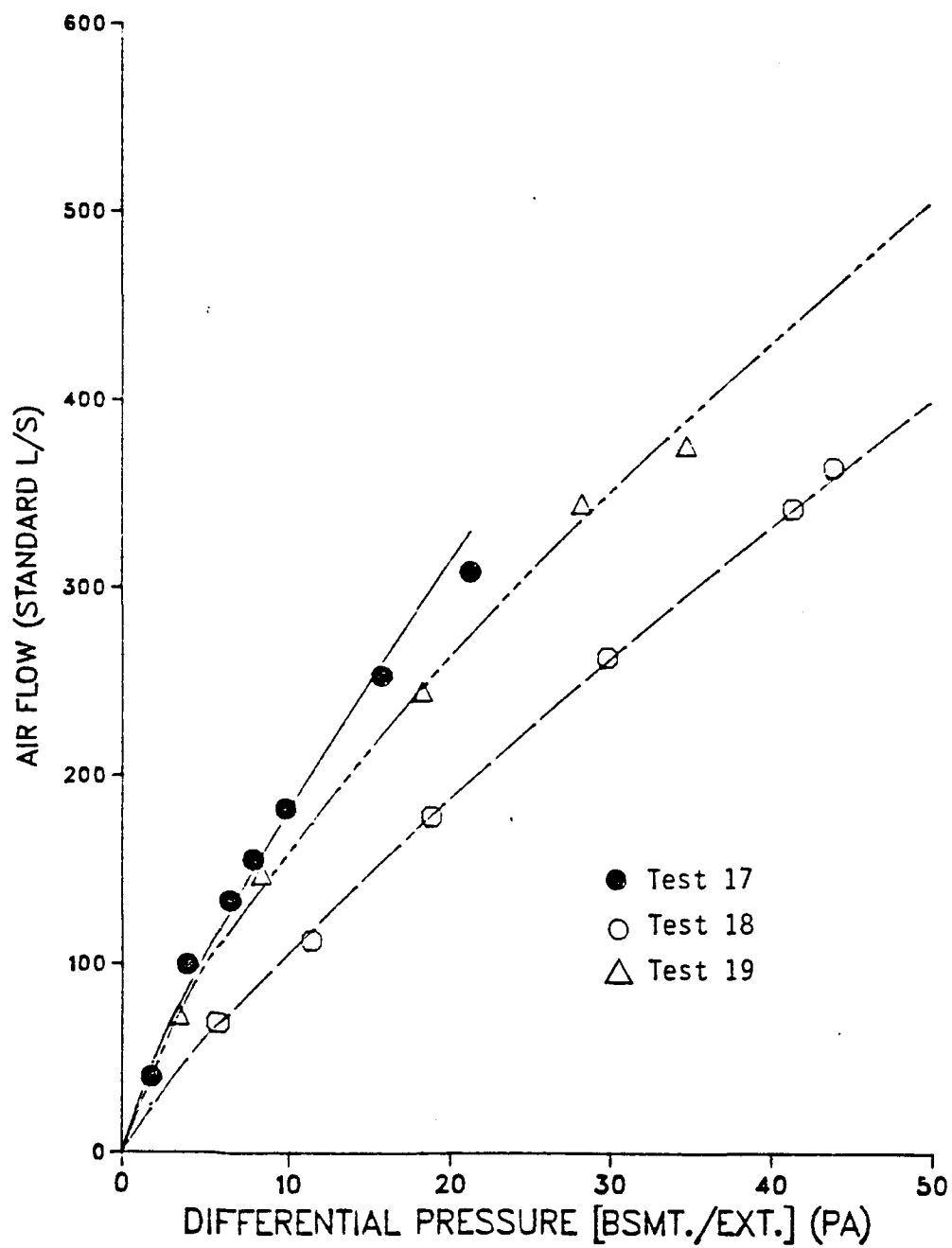


Fig. 9 Tests 17 to 19

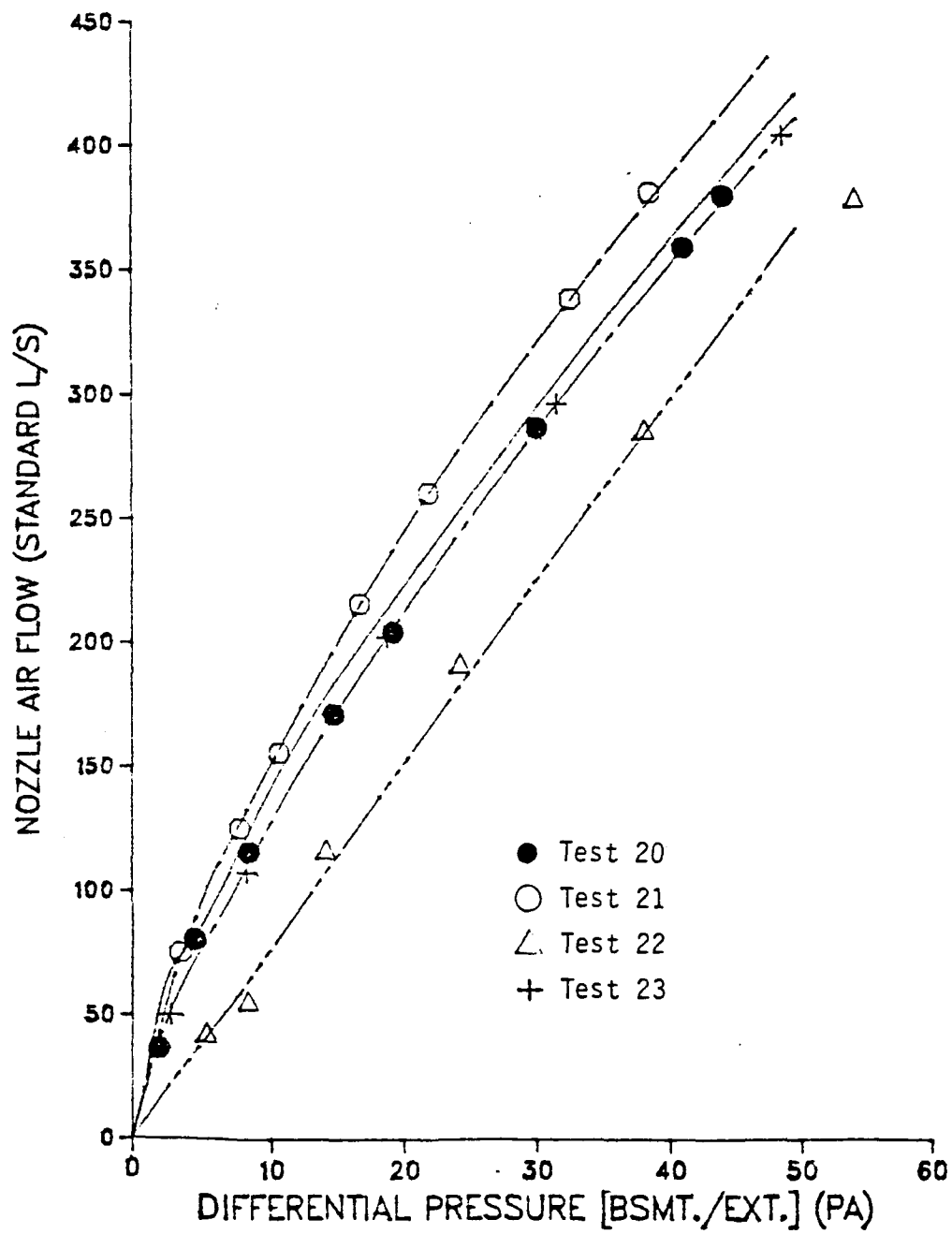


Fig. 10 Tests 20 to 23

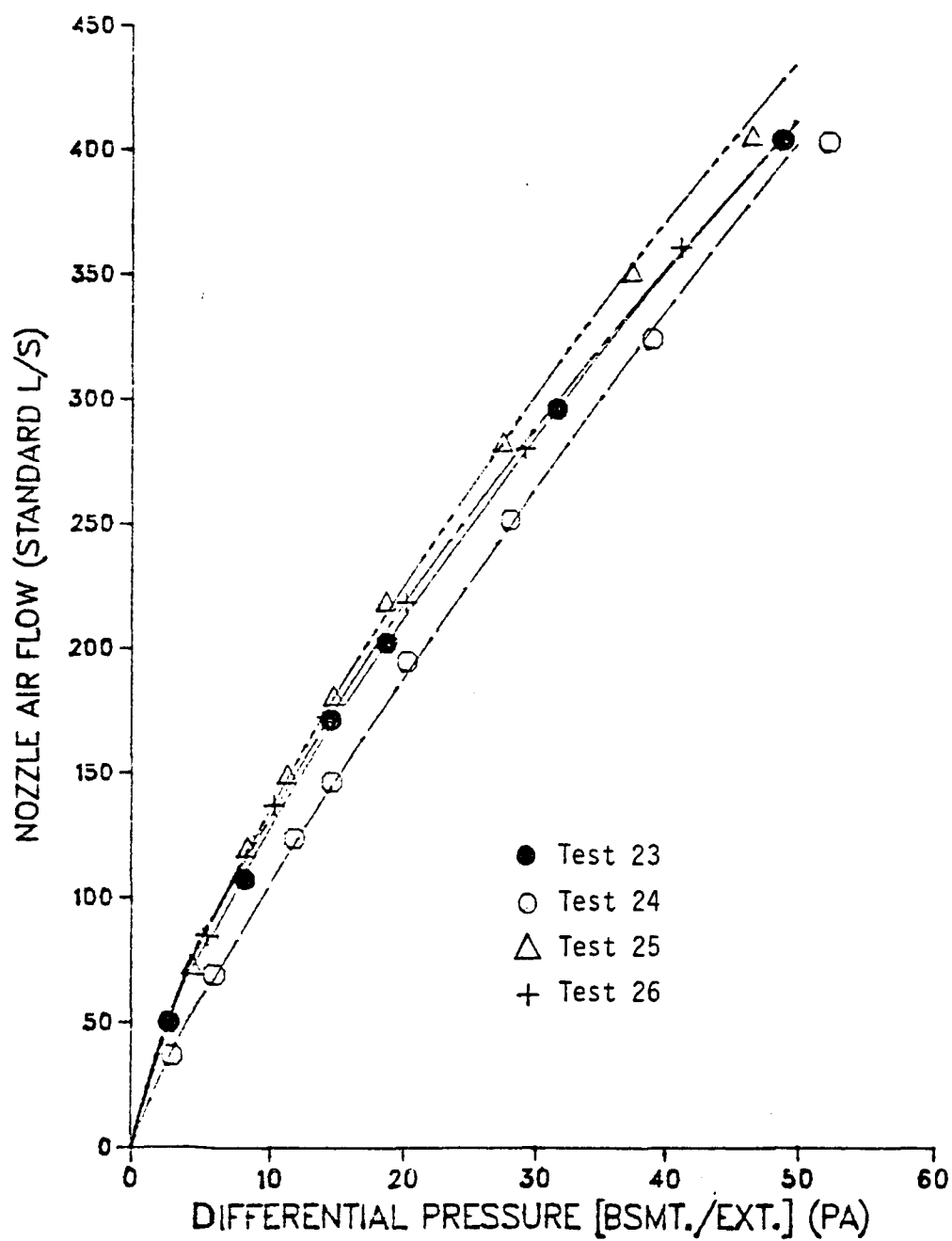


Fig. 11 Tests 23 to 26

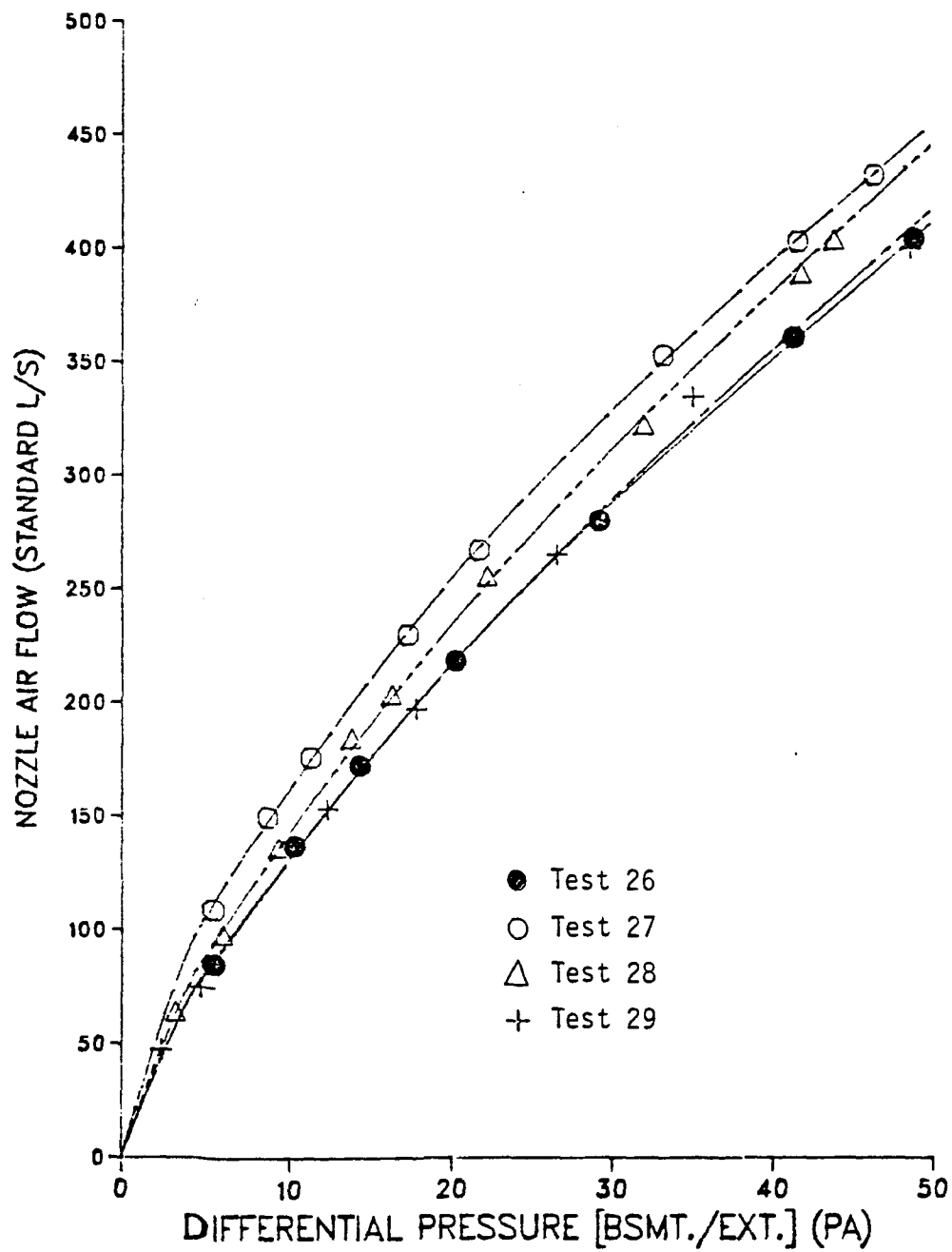
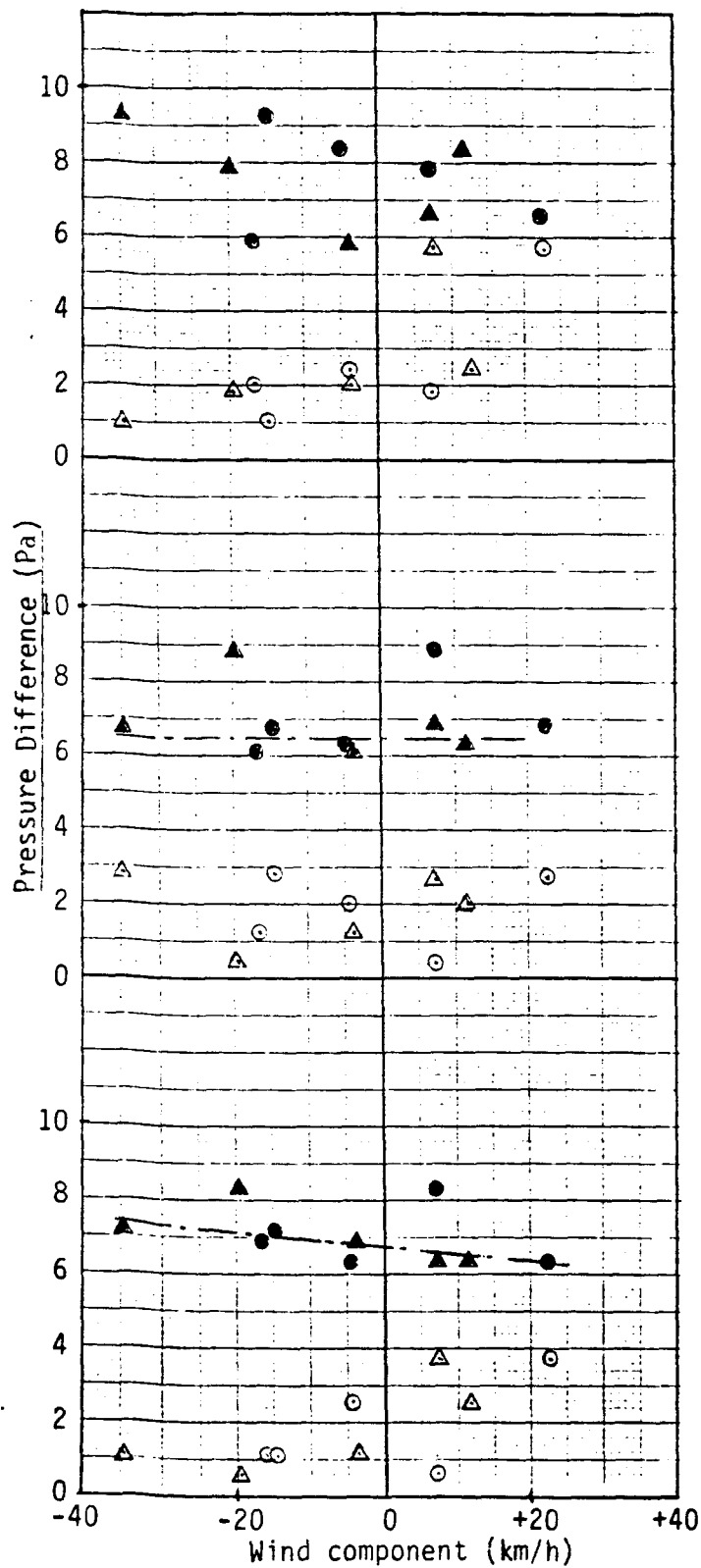


Fig. 12 Tests 26 to 29



13a. Pressure differences between kitchen and south-wall tap.

13b. Pressure differences between kitchen and 4-way tap.

13c. Pressure differences between basement and 4-way tap.

Legend:

- △ - Background press. diff. versus south wall vector.
- - Background press. diff. versus east wall vector.
- ▲ - Change caused by Jenn-Air versus south wall vector.
- - Change caused by Jenn-Air versus east wall vector.

Fig. 13. Effects of wind on background pressure difference and Jenn-Air depressurization

**Saskatchewan Research Council
15 Innovation Blvd.
Saskatoon, Saskatchewan
Canada
S7N 2X8**

2. OBJECTIVES OF THE STUDY

The primary objectives of the study were as follows:

- To measure the depressurizing effects caused by the individual operation of three selected exhaust appliances.
- To investigate the combined depressurization effects of two or more exhaust systems operating together.
- To investigate the effectiveness of remedial measures, in the form of outside air ducted to the vicinity of the exhaust system.
- To investigate the changes in thermal comfort caused by the introduction of cold outside air.
- To investigate a specific remedial system consisting of a fan which forces outside air through an inlet duct to a point close to the furnace - creating a high pressure zone for a limited period during furnace start-up. This ingenious solution has been suggested by Dr. G. K. Yuill.
- To investigate the effect of wind on selected operational configurations and their measured performance.