#6425

FINAL REPORT

HOUSE DEPRESSURIZATION TOLERANCE OF MID-EFFICIENCY GAS FURNACES

CR FILE # 6718 - 12
SHELTAIR JOB # 90170

Submitted to:

Research Division
Canada Mortgage and Housing Corporation
National Office
682 Montreal Road
OTTAWA, Ontario
K1A 0P7

Submitted by:

Sheltair Scientific Ltd.
#2 - 3661 W. 4th Ave.
Vancouver, B.C.
V6R 1P2

December, 1990

Figures

Tables

Table of Contents

Summary

The unexpected spillage of combustion gasses from induced draft furnaces has raised concern over the suitability of these appliances for tighter Canadian houses and for houses or furnace rooms where depressurization is a likely occurrence. Reasons for spillage include leaky fan assemblies and other design flaws, manufacturing defects and poor installation practice. Problems hae been witnessed with both side-wall vented induced-draft furnaces, and induced draft furnaces connected to naturally aspirated vertical chimneys.

The issue of combustion products spillage by mid-efficiency gas furnaces was raised at a Canadian Home Builders Association (CHBA) Technical Research Committee meeting in 1989, at which time the CMHC Research Division agreed to assist in providing technical support. The Canadian Gas Association (CGA) was advised of CMHC's intentions, and agreed to share information on their own activities in this area, and to review the technical issues raised by this project.

The project was designed to address a number of objectives including determining the nature and extent of the problem, predicting impacts on indoor air quality (IAQ), advising manufacturers, heating trades and inspection authorities, and assisting CGA in developing standards and test methods for categorizing appliances according to their house depressurization tolerance.

The work plan included surveying a full range of I.D. appliances, conducting lab tests, modeling IAQ, visiting Canadian manufacturers of furnaces, and recommending an appropriate response for government and industry.

The majority of induced draft appliances tested in the field were found to spill combustion gases under normal operating conditions. The quantity of spillage increases exponentially as house depressurization increases from 0 to 20 Pascals. The percentage of combustion gas that spills indoors is greater for appliances with larger fuel input rates.

Combustion gases spill down stream of the induced draft blower, at the fan axle hole, joins in the blower housing, the connection between the furnace and the vent connector, and at joins in the vent connector. The

location and quantity of leakage varies by appliance manufacturer and installation practice. Induced Draft boilers and DHW appliances share the same problems identified with induced draft furnaces.

An airtight test chamber can be used to accurately calculate the generation rates of CO_2 caused by spillage from two models of mid-efficiency furnaces. The generation rate of CO_2 at 0 Pascals of chamber depressurization was 0.52 Litres/minute for Furnace A, and 0.34 minutes for Furnace B.

The generation rate at 20 Pa of chamber depressurization was 6.11 L/min for Furnace A, and 10.78 L/min for Furnace B. This quantity of spillage represents 14% and 17% of the total combustion gas for each of these furnaces. (or 17% of the combustion gases). The impact on generation rates from sealing joins of the vent connector is marginal.

A typical new house can be modelled using a combined Enerpass/Contam computer simulation program. Predicted levels of CO_2 with without any contribution from furnace spillage reach a maximum of 802 ppm on the main floor and 704 ppm in the basement (based on 3 person occupancy).

With contribution from furnace spillage, CO_2 levels range from a maximum of 1177 ppm at 5 Pa of depressurization to a maximum of 3570 PPM at 20 Pa of depressurization. These levels represent a possible concern for occupant comfort, and would require increased house ventilation.

NO_2 levels range from 0.25 ppm at 5 Pa to 1.4 ppm at 20 Pa. These levels exceed Canadian Health and Welfare Guidelines for indoor air quality, as well as exceeding many foreign standards. Average NO_2 levels also exceed concentrations measured by other researchers, in houses where a link has been made between acute respiratory disease in children, and gas cooking.

CO never exceeded 0.23 PPM and is not likely to be a health or comfort concern as long as furnaces are properly maintained.

During the seminars, manufacturers representives agreed that eliminating spillage would require low cost, relatively simple design changes to the induced draft fan housing, and possible changes to vent connector design.

For reasons of health, comfort and consumer confidence it may be imperative that the gas industry modify the design of mid-efficiency furnaces to eliminate spillage potential.

An energy efficient appliance should be defined as an appliance that burns fuel efficiently ***and is designed to operate in an energy efficient house.***

Condensing gas furnaces with sealed combustion are too expensive for low-end housing, and will frequently be impossible to justify on energy payback analysis. Since new energy efficiency codes will apply to all segments of the housing market, it is vital that mid-efficiency appliances become suitable for use in energy efficient houses.

Mid-efficient appliances should be capable of operating under house depressurization levels that maintain the integrity of the envelope, with no measurable combustion gas spillage.

Code requirements for combustion/replacement air ducts for mid-efficiency furnaces should be eliminated. A combustion air supply gives a false sense of safety, it is ineffective at improving the operational safety of mid efficiency gas appliances, and it imposes major cost penalties on builders and homeowners.

CGA should make changes to B149 and draft a manufactures test procedure for energy efficient appliances that is more comprehensive than the DOE tests. It is recommended that such a test procedure include the use of a test chamber similar to the one designed and constructed for this research because of its ease of construction, low cost, and air tightness characteristics.

Gas Safety authorities and building inspectors have been lax in enforcing manufacturers requirements for the sealing of vent connectors. It is recommended that an industry bulletin be drawn up to alert inspectors to the importance of sealing flue connectors.

RÉSUMÉ

TOLÉRANCE DES APPAREILS DE CHAUFFAGE AU GAZ À TIRAGE INDUIT À LA DÉPRESSURISATION DE L'HABITATION

On a constaté dans certaines maisons l'émanation de produits de combustion provenant d'appareils de chauffage au gaz à tirage induit. Cela n'était pas prévu. Le tirage induit était sensé pouvoir contrer la dépressurisation de l'habitation.

Un grand nombre d'appareils de chauffage à efficacité moyenne utilisent un ventilateur induisant le tirage pour forcer les gaz de combustion à travers l'échangeur de chaleur. Certains modèles dotés d'évents spéciaux utilisent également la pression du ventilateur pour forcer l'évacuation des produits de combustion en dehors de la maison par des évents placés dans les murs latéraux. D'autres appareils à rendement modéré utilisent la poussée thermique des produits de combustion pour provoquer la ventilation par une cheminée verticale. Un troisième type de générateur à rendement modéré ne recourt pas au tirage induit mais est aspiré naturellement et utilise un système de réglage pour améliorer son rendement calculé.

L'efficacité moyenne deviendra bientôt une norme minimale pour tous les générateurs aux États-Unis et dans certaines régions du Canada. Les appareils à tirage induit sont également utilisés par les entrepreneurs, car c'est un moyen simple d'éviter les émanations de combustion et de se conformer à la norme CSA F326 relative aux systèmes de ventilation mécaniques résidentiels et au Code national du bâtiment pour 1995. L'obligation de satisfaire aux objectifs globaux relatifs à la réduction du gaz carbonique et à l'économie d'énergie rendra également les appareils à rendement modéré plus populaires, mais c'est la tendance vers des habitations éco-énergétiques et étanches à l'air qui est plus significative. Les appareils de combustion doivent pouvoir tolérer des dépressurisations de l'habitation de l'ordre de 20 Pascals.

Plusieurs appareils ont été testés in situ, et la plupart produisaient des émanations dans des conditions normales de fonctionnement. Deux générateurs ont été installés dans une cuve d'essai étanche pour calculer la quantité d'émanations en fonction de la dépressurisation. Le gaz carbonique est le principal produit de combustion. On a constaté des taux de production de gaz carbonique de 0,52 et 0,34 litresminute sans dépressurisation de la cuve. À une dépressurisation de la cuve de 20 Pascals, le taux d'émanations a augmenté à 6,11 litresminute et 10,78 litresminute. Ceci représente 14 et 17% des gaz de combustion, qui contiennent également des oxydes d'azote et de l'humidité.

Une expérience contrôlée d'heure en heure, faisant entrer en ligne de compte des fuites d'air, le fonctionnement d'un système mécanique et des concentrations de polluants a été effectuée pour déterminer les concentrations de polluants auxquels seraient exposés les occupants dans des conditions de fonctionnement normal. Les niveaux prévus de gaz carbonique ont atteint un maximum de 800 ppm, sans émanation de générateur, pour une maison canadienne typique. Lorsqu'on fait entrer dans l'expérience les émanations d'un générateur (en ignorant le fait qu'un chauffe-eau domestique répandrait également des émanations), les niveaux prévus ont atteint 1 200 ppm avec un taux de dépressurisation de la maison de 5 Pa et 3 600 ppm à 20 Pa. Ces

niveaux dépassent de 1 000 ppm les normes de confort pour le gaz carbonique et de 3 500 ppm les normes sanitaires, ce qui laisse à penser qu'il en résulterait des maux de tête et autres symptômes. Les concentrations prévues d'oxyde d'azote se situaient entre 0,25 ppm à 5 Pa et 1,4 ppm à 20 Pa de dépressurisation de la maison. Ces niveaux dépassaient les directives de Santé et Bien-être social Canada pour la qualité de l'air ambiant. L'oxyde de carbone n'a jamais dépassé 0,23 ppm et ne devrait pas présenter de danger pour ce type d'appareil.

Il est possible d'apporter des modifications relativement peu onéreuses à la production, la conception et l'installation des générateurs pour réduire substantiellement les émanations de combustion. Un meilleur contrôle de la qualité et une évaluation plus rigoureuse des appareils à gaz quant à leur tolérance à la dépressurisation des habitations éviteraient une dégradation de la qualité de l'air ambiant due à l'utilisation croissante de ces appareils. Afin d'améliorer l'efficacité énergétique des habitations, il faut disposer d'appareils qui sont, non seulement éco-énergétiques eux-mêmes, mais également adaptés à une utilisation dans un environnement étanche.

1.0 Introduction

1.1 Background

The unexpected spillage of combustion gasses from induced draft furnaces has raised concern over the suitability of these appliances for tighter Canadian houses and for houses or furnace rooms where depressurization is a likely occurrence. Reasons for spillage include leaky fan assemblies and other design flaws, manufacturing defects and poor installation practice. Problems have been witnessed with both side-wall vented induced-draft furnaces, and induced draft furnaces connected to naturally aspirated vertical chimneys.

The issue of combustion products spillage by mid-efficiency gas furnaces has been brought to a head in Canada for what we believe are three main reasons. The first reason is Canada's severe climate that influences the design and construction of the envelope of houses. The second reason is the availability and popularity of natural gas fuel which influences our choice of appliances. The third reason is a concerted effort to improve upon the performance of our houses in all areas (combustion safety, moisture control, air quality, upkeep and fire safety, and energy efficiency of the envelope and appliances). This has necessitated a new philosophy in the housing industry where we treat a "house as a system".

The housing industry is increasingly relying on mid-efficiency furnaces as a way to avoid pressure induced spillage and associated air quality hazards in new housing. Moreover mid-efficiency models, are expected to become a mandatory minimum requirement in the U.S.A. and parts of Canada in the next two years. Some jurisdictions in Canada have already proposed efficiency standards which require, at a minimum, installation of mid-efficiency gas furnaces.

Mid-efficiency is also expected to become a common strategy for builders who want to easily meet the requirements of the CSA F326 Ventilation Standard which is being proposed in the 1995 National Building Code. Also the requirement to meet global carbon dioxide generation goals, and to conserve energy, is expected to increase the shift away from naturally aspirated appliances. The trend towards the building of tighter houses across Canada has been well established by two surveys of airtightness in 1980-82[1] and 1990.[2] For all of these reasons it is desirable to investigate thoroughly the impact on houses of power vented combustion appliances, and ensure that we are not inadvertently creating new problems while fixing the old ones.

The issue of combustion products spillage by mid-efficiency gas furnaces was raised at a Canadian Home Builders Association (CHBA) Technical Research Committee meeting in 1989, at which time the CMHC Research Division agreed to assist in providing technical support. The Canadian Gas Association (CGA) was advised of CMHC's intentions, and agreed to share information on their own activities in this area, and to review the technical issues raised by this project.

1.2 Objectives

This project was designed to address the following five objectives:

1. determine the nature and scope of spillage from combustion venting systems connected to a variety of induced draft appliances;
2. predict the impact of spillage on indoor air quality for different combustion systems and operating scenarios;
3. advise manufacturers of improved design features that can be incorporated into existing models of induced draft appliances;

---

[1] "Airtightness Tests on 200 New Houses Across Canada: Summary of Results," Bett Publication No. 84.01, Prepared by Michael Sulatisky, for EMR Canada, January, 1984.

[2] "Ventilation and Airtightness in new detached houses", May 1990, by Tom Hamlin et al, CMHC.

4. advise heating trades and inspection authorities of improved installation practices that can help prevent or minimize combustion gas spillage from induced draft gas appliances; and,
5. assist CGA committees in developing standards and test methods for categorizing appliances according to their house depressurization tolerance.

1.3 General Approach

The work plan for this project broke down into six stages as outlined below:

1. survey a full range of induced draft gas appliances including side vented and vertically vented furnaces, boilers, water heaters, and draft inducer kits;
2. construct a test facility in the lab;
3. test two different induced draft furnaces in the lab in order to quantify the combustion gas spillage under conditions of varying degrees of depressurization;
4. visit CGA and four leading manufacturers of induced draft gas furnaces sold in Canada;
5. use sophisticated software to model indoor air quality during a variety of spillage scenarios; and,
6. evaluate the severity of air quality problems created by combustion gas spillage, and recommend on appropriate responses for government and industry.

2.0 Field Survey of Induced Draft Appliances

2.1 Procedures

A test procedure for identifying combustion gas spillage from Induced draft appliances was developed. The test was modelled on a procedure used by Sheltair during similar research for Energy Mines and Resources Canada.[3] Essentially the procedure involves using a blower door to create varying degrees of house depressurization, while firing the appliance and timing the duration of spillage. Spillage locations are also noted, along with the performance of any safety devices on the appliances. Actual levels of CO_2 are measured at each potential spillage location, in order to roughly approximate the severity of spillage.

[3]An outline of this test procedure can be obtained from our earlier report on **House Depressurization Limits for Mid-Efficiency Gas-Fired Furnaces**, Energy Mines and Resources Canada, 1989.

2.2 Selection of Houses and Equipment

A brief description of the houses and equipment included in the field survey is provided in tabular form below:

A description of Test Houses and Appliances.	
1.	**House:** A 2 year old slab-on-grade R-2000 house built in Delta, B.C. **Appliance:** An Amana Air Command Furnace vented with a 5 meter high B-vent that connects directly t the appliance. The DHW tank was a separately vented sealed combustion unit manufactured by State.
2.	**House:** A new 350m² conventionally built house located in the district of North Vancouver, B.C. on the Indian Arm Inlet. **Appliance:** A Carrier Bryant Furnace that is commonly vented with a JetGlass naturally aspirated DHW tank. The chimney is 9 meters in length. Some joins in the Flue connector were sealed. Both appliances were located in an unfinished basement.
3.	**House:** A new two storey house with a full height basement located in New Westminster, B.C. **Appliance:** An ICG Ultimate II Furnace that is located in a small furnace room off a finished basement. The furnace is commonly vented with a naturally aspired John Wood DHW heater. The B-vent is 7 meters in length.
4.	**House:** A 2 year old energy efficient demonstration house with a floor area of 250 m². The house is located in New Westminster, B.C. The house has a special exhaust only ventilation system manufactured in France. **Appliance:** An airco Turbo 8300 Furnace that is side vented a the back of the house. The furnace is located in semi-finished basement approximately 5 meters from the outside wall. The side vented chimney use B-vent horizontally mounted. A State water heater is installed separate from the furnace.
5.	**House:** A 2 storey, 35 year old house with several additions located in Vancouver, next to the ocean. **Appliance:** The house has two Lennox Conservator 3 Furnaces that are separately ducted and controlled. The furnaces are vented into an unlined masonry chimney on an exterior wall. A DHW tank is vented separately into the same chimney. All appliances are installed in a workroom in the above grade basement.

	A description of Test Houses and Appliances.
6.	**House:** A 3 year old R-2000 house built in Burnaby, B.C. **Appliance:** A side vented Hydro-Therm Boiler with a DHW hot water loop. The galvanized metal vent was severely corroded, and the siding was stained. The continuous flexible chimney was not sealed at the hood or at the I.D. fan.
7.	**House:** A new 400 m2 quality plus house built in North Vancouver. The house had a total of 4 induced draft appliances. **Appliance:** A John Wood Side Vented DHW tank. The chimney was sealed with silicone. The standing pilot spilled indoors when the appliance was not operating.
8.	**House:** A new 500 m^2 quality plus house built in Coquitlam B.C. The house had 2 I.D. appliances. **Appliance:** A Jetglass side vented DHW tank. The 10m chimney was partially metal and partially plastic. Joins in the metal were not sealed.
9.	**House:** A training room at the B.C. Gas Service Department in Burnaby. **Appliance:** A field power venting kit was used to side vent a conventional DHW tank. The field fan was mounted on the outside of the exterior wall of the building. The venting kit is available and approved for installation in B.C. No joins were sealed in the horizontal chimneys.
10.	**House:** A training room at the B.C. Gas Service Department in Burnaby. **Appliance:** A Tjernlund power venting kit was used to side vent a natural gas furnace. The Tjernlund Fan was mounted on the inside of the exterior wall. The unit is available and approved for installation in B.C. no joins were sealed in the horizontal chimney.
11.	**House:** A new 300m^2 quality plus house in Surrey, B.C. **Appliance:** A naturally aspirated furnace and DHW tank vertically vented. A power venter was added horizontally at the top or the vertical chimney. A controls kit was installed on both appliances; some problems were encountered because the appliances were over sized and the chimney was undersized, and very leaky.

Some difficulty was encountered in locating power venting kits since these are seldom used at present in residential buildings in British Columbia. Sheltair was required to organize installation of a fan powered I.D. kit in a house with a natural draft furnace and water heater, in order to permit complete testing of this configuration. This involved working closely with the distributer of Field controls in British Columbia, Ontor Ltd., with B.C. Hydro, B.C. Gas, the builder (Rob Morrison), and the installer. Despite all this organization and planning, problems were still encountered with the installation. House #11 was used for this demonstration. The furnace installed was 4 times larger than required for the heat load of the house. The results of the field tests were considered invalid and are not reported upon.

To provide more reliable and additional information on the performance of power venter kits, tests were also conducted in B.C. Gas laboratory in Burnaby. This lab has two different power venter kits, a Field and a Tjernlund, permanently installed. Although these units are intended to be used as demonstrations for training purposes, installation was not dissimilar from what might be expected to occur in houses, and the test results are expected to be representive.

2.3 Results

The field test results for each of the induced draft appliances has been summarized below, in the order which the tests were conducted at the houses. Also, included with these results, for reference purposes, are results on the original five induced draft furnaces tested using similar test protocol.

1. **Do combustion gases spill indoors under normal operating conditions without house depressurization?**[4]

Appliance type	Field Observation	Comments
Furnaces:		
1. Input 70,000 BTU Amana Model GC170A30C	No	
2. Input 71,000 BTU Carrier Model 395 BAW024060	Yes	
3. Input 105,000 BTU ICG Model MGF 105N	Yes	
4. Input 45,000 BTU Airco Model TH455	Yes	
5. Input 75,000 BTU Lennox Model G16 Q3-75-C1	Yes	
Boiler:		
6. Input 85,000 BTU Hydrotherm Model HI85F	Yes	excessive spillage from openings in boiler housing
DHW Heater:		
7. Input 40,500 BTU John Wood Model JW502V-80904	No	
8. Input 40,000 BTU Jet Glass Model M-1-TW 50S5LN-6	Yes	spillage at joints of flue connector
Power Venter:		
9. Input 28,000 BTU *Field Model Kenmore C643-736341	No	
10. Input 135,000 **Tjernlund Model Super Hot SG135	Yes	excess spillage from fan housing

*Field was connected to a Kenmore DHW heater
**Tjernlund was connected to a Super Hot conventional boiler

[4]Numbers refer to houses described previously.

2. Do increases in house depressurization levels cause spillage qualities to increase?

Appliance type	Field Observation	Comments
Furnaces:		
1. Input 70,000 BTU Amana Model GC170A30C	Yes	began to spill 25 Pa
2. Input 71,000 BTU Carrier Model 395 BAW024060	Yes	steady increase
3. Input 105,000 BTU ICG Model MGF 105N	Yes	slight increase
4. Input 45,000 BTU Airco Model TH455	Yes	slight increase
5. Input 75,000 BTU Lennox Model G16 Q3-75-C1	Yes	high spillage @ 15 Pa
Boiler:		
6. Input 85,000 BTU Hydrotherm Model HI85F	Yes	increased spillage from all locations
DHW Heater:		
7. Input 40,500 BTU John Wood Model JW502V-80904	Yes	slight decrease to 20 Pa then increase
8. Input 40,000 BTU Jet Glass Model M-1-TW 50S5LN-6	Yes	excessive spillage from flue
Power Venter:		
9. Input 28,000 BTU *Field Model Kenmore C643-736341	No	only spillage at inlet to combustion chamber
10. Input 135,000 **Tjernlund Model Super Hot SG135	No	excess spillage from fan housing

3. **What is the shut down response time for the furnace in the event that major spillage occurs at the vent safety switch?**

Appliance type	Time (sec.)	Pressure Pa	Comments
Furnaces:			
1. Input 70,000 BTU Amana Model GC170A30C	20	30	
2. Input 71,000 BTU Carrier Model 395 BAW024060	-	20	did not shut down
3. Input 105,000 BTU ICG Model MGF 105N	32	50	
4. Input 45,000 BTU Airco Model TH455	-	50	did not shut down
5. Input 75,000 BTU Lennox Model G16 Q3-75-C1	-	-	no vent safety switch (old model)
Boiler:			
6. Input 85,000 BTU Hydrotherm Model HI85F	-	30	
DHW Heater:			
7. Input 40,500 BTU John Wood Model JW502V-80904			no major spillage
8. Input 40,000 BTU Jet Glass Model M-1-TW 50S5LN-6	-	50	
Power Venter:			
9. Input 28,000 BTU *Field Model Kenmore C643-736341		40	no shut down
10. Input 135,000 **Tjernlund Model Super Hot SG135	120	40	gas valve shut be pressure switch

4. At what house depressurization level will the appliance/chimney fail to establish an up-draft?

Appliance type	Depressurization Pa	Comments
Furnaces:		
1. Input 70,000 BTU Amana Model GC170A30C	30	
2. Input 71,000 BTU Carrier Model 395 BAW024060	15	
3. Input 105,000 BTU ICG Model MGF 105N	22	up-draft failed after 55 sec.
4. Input 45,000 BTU Airco Model TH455	-	established up-draft @ 50 Pa
5. Input 75,000 BTU Lennox Model G16 Q3-75-C1	-	established up-draft @ 20 Pa
Boiler:		
6. Input 85,000 BTU Hydrotherm Model HI85F	35	Pressure switch did not allow start-up
DHW Heater:		
7. Input 40,500 BTU John Wood Model JW502V-80904		
8. Input 40,000 BTU Jet Glass Model M-1-TW 50S5LN-6	-	though most of flue gases were spilling from joints, chimney maintained draft
Power Venter:		
9. Input 28,000 BTU *Field Model Kenmore C643-736341	-	venter maintained draft @ high pressure
10. Input 135,000 **Tjernlund Model Super Hot SG135	-	venter maintained draft @ high pressure

5. If a DHW heater shares the same flue as the furnace, at what pressure does the system fail to establish an up-draft?

Appliance type	Depressurization (Pa)	Comments
Furnaces:		
1. Input 70,000 BTU Amana Model GC170A30C	-	no shared appliance
2. Input 71,000 BTU Carrier Model 395 BAW024060	10	
3. Input 105,000 BTU ICG Model MGF 105N	15	
4. Input 45,000 BTU Airco Model TH455	-	no shared appliance
5. Input 75,000 BTU Lennox Model G16 Q3-75-C1	10	
Boiler:		
6. Input 85,000 BTU Hydrotherm Model HI85F	-	no shared appliance
DHW Heater:		
7. Input 40,500 BTU John Wood Model JW502V-80904	-	DHW on its own chimney
8. Input 40,000 BTU Jet Glass Model M-1-TW 50S5LN-6	-	DHW on its own chimney
Power Venter:		
9. Input 28,000 BTU *Field Model Kenmore C643-736341	-	no shared appliance
10. Input 135,000 **Tjernlund Model Super Hot SG135	-	no shared appliance

6. After blocking flue pipe completely at the point of exit, how long did it take for appliance to shut down with no house depressurization?

Appliance type	Observed Time (sec.)	Comments
Furnaces:		
1. Input 70,000 BTU Amana Model GC170A30C	5	no shared appliance
2. Input 71,000 BTU Carrier Model 395 BAW024060	300	
3. Input 105,000 BTU ICG Model MGF 105N	105	
4. Input 45,000 BTU Airco Model TH455	-	no shut down
5. Input 75,000 BTU Lennox Model G16 Q3-75-C1	19	
Boiler:		
6. Input 85,000 BTU Hydrotherm Model HI85F	0	pressure switch prohibited boiler operation
DHW Heater:		
7. Input 40,500 BTU John Wood Model JW502V-80904	-	no shut down after 5 min.
8. Input 40,000 BTU Jet Glass Model M-1-TW 50S5LN-6	-	no shut down after 5 min.
Power Venter:		
9. Input 28,000 BTU *Field Model Kenmore C643-736341	-	appliance would not shut down due to bad seal @ exit
10. Input 135,000 **Tjernlund Model Super Hot SG135	60	pressure switch effected shut down

2.4 Insights From The Field

The field survey results indicate that it is difficult to generalize about induced draft appliances. The wide range in performance emphasizes the need of each manufacturers' appliance to be tested according to a standard.

Some highlights from the field survey are listed below:

- the gas-fired induced-draft boilers had similar performance to induced draft furnaces;
- The John Wood induced draft DHW heater exhibited no combustion gas spillage.
- The Field power venter kit performed poorly when connected to a poorly installed venting system. On the other hand the Field power venter kit performed extremely well when connected to a well designed venting system
- The Tjernlund power venter kit, (located inside the house), leaked around the fan housing and axle, as well as down stream of the induced draft.
- The Jet Glass DHW tank had spillage from the I.D. fan and from numerous joins along a lengthy chimney.

3.0 Lab Testing

3.1 Chamber Design and Operation

A test chamber was designed to allow for quantification of the combustion gas spillage occurring under various levels of house depressurization. Photographs of this test chamber are presented in Figure 1, (a,b,c, & d) and a schematic is presented in Figure 2. The test chamber was an eight foot cube built out of foil-faced Thermax board, taped at the seams. This approach provided for a quick, air tight, and light weight assembly. It also provided sufficient room for testing two induced-draft gas furnaces side by side. The Thermax board is rigid and relatively strong, but can be cut with a utility knife. This allowed for easy installation of air conditioning equipment, exhaust and supply ducts, air circulating systems, flue terminals, sky lights and doors.

A Sciemetrics data acquisition system and an MS DOS computer were used to monitor performance of the test chamber, including the following parameters: air pressures, carbon dioxide, carbon monoxide, humidity, temperature, air flows, and tracer gas concentrations. All of these measurements were taken both inside and outside of the test chamber.

In addition, composition of combustion gasses was monitored, as well as the pressures in the flue outlet box on top of the chamber. Sampling locations within the test chamber are illustrated in Figure 3.

Some of the special features of the chamber that may be of interest include:

- extensive air sealing of the circulating air plenums in the chamber to avoid air leakage through ducts,
- location of the chamber next to a loading bay of the building so that outdoor temperatures could be easily maintained, and so that the combustion products could be exhausted well outside of the building.

- use of an air conditioner to carefully control temperatures at a constant 18°C within the chamber, and
- use of the fan from the air conditioner to assist in mixing pollutants evenly within the chamber.

The flue gas collection box on top of the chamber provided complete control of the venting pressures. It also allowed a comparison of two approaches to testing appliances - first by depressurising the furnace room, and second by modulating flue outlet pressures.

Figure 1: Photographs of Test Chamber

Photo "A"

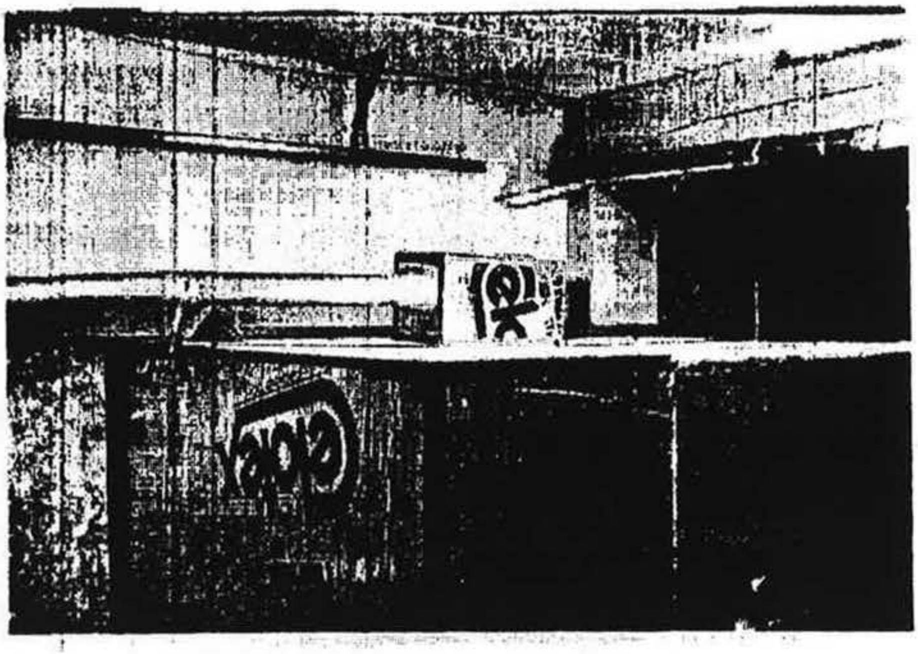


Photo "B"

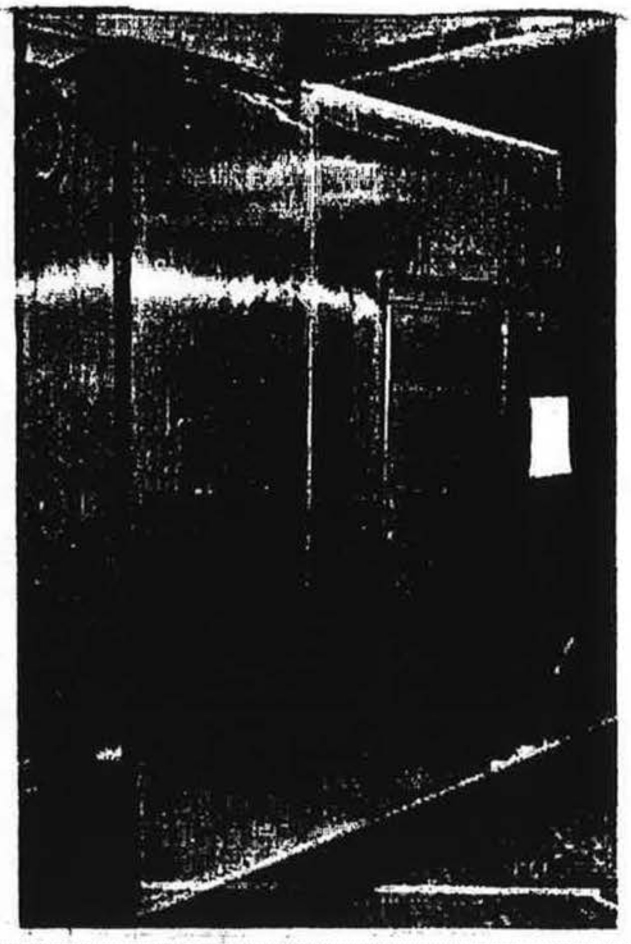


Figure 1 Continued: More Photographs of Test Chamber

Photo "C"

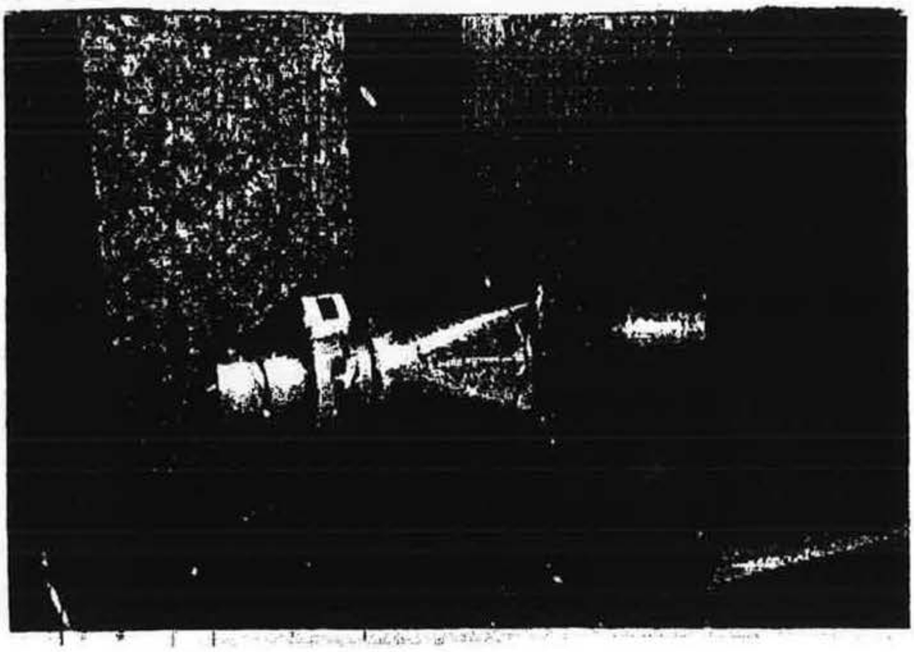


Photo "D"

Figure 2: Schematic of Test Chamber

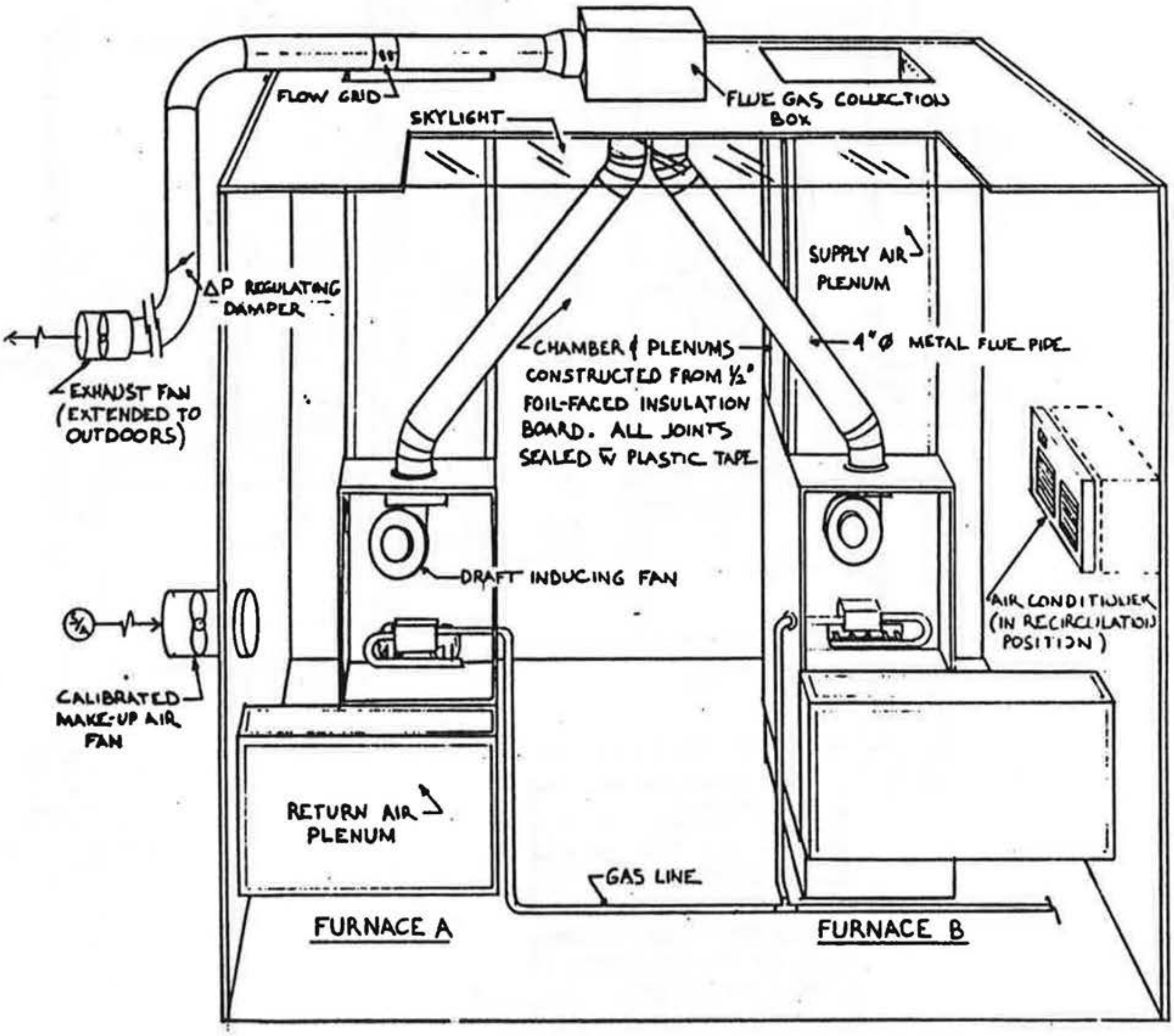
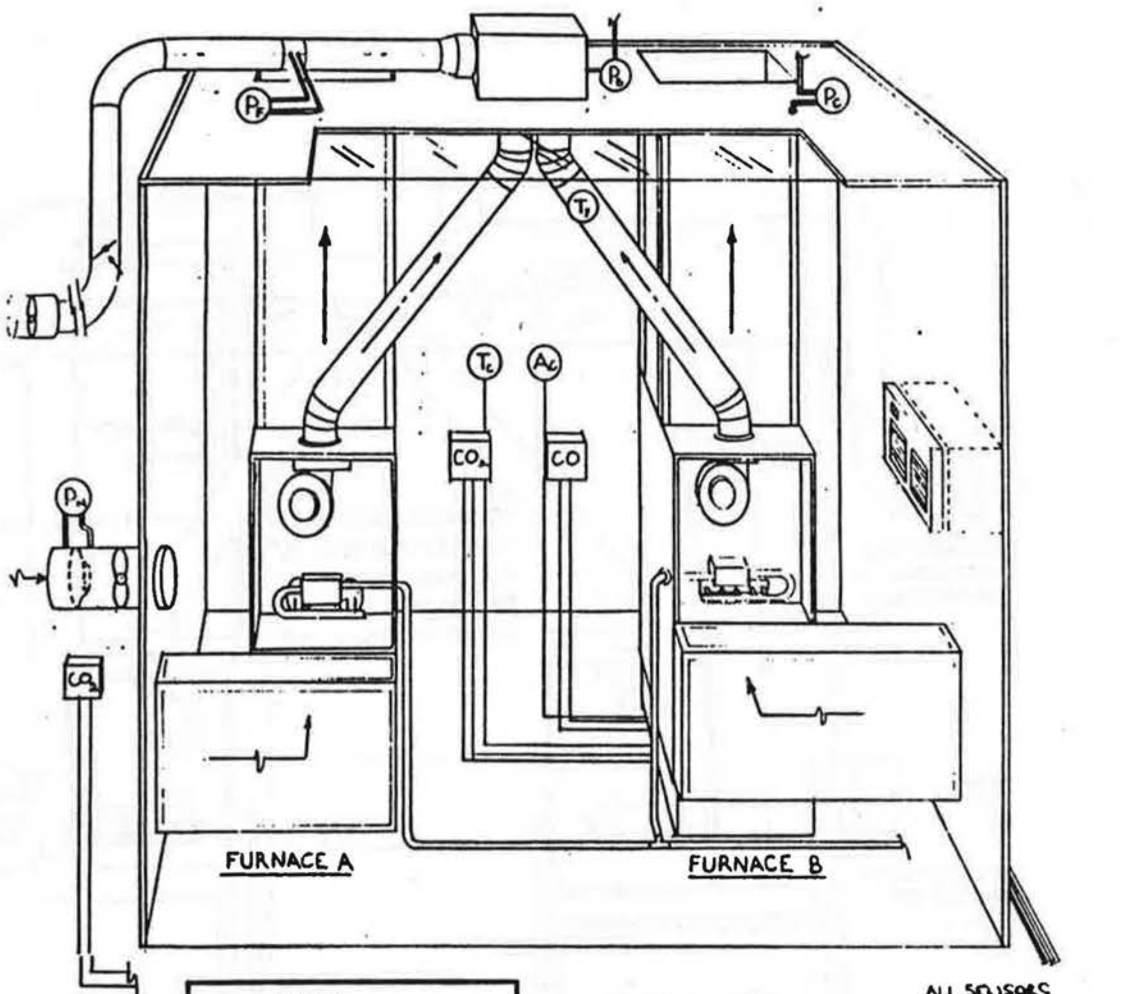


Figure 3: Sensor Locations for Test Chamber



Legend	
Symbol	**Description**
P_C	Chamber pressure differential
P_B	Collection box pressure
P_F	Flow pressure for exhaust gases
P_M	Make-up air flow pressure
CO_2	Chamber CO_2 level
CO	Chamber CO level
A_C	Chamber absolute humidity level
CO_2	Outdoor CO_2 level
T_C	Chamber temperature
T_F	Flue gas temperature

3.2 Test Protocol for Combustion Gas Spillage Test

The following is a step by step outline of the test procedures and can be used by manufactures or researchers to duplicate the tests performed by Sheltair on mid-efficiency furnaces:

1. Initialize and calibrate all equipment. Zero all gauges, pressure transducers, and the combustion analyzer efficiency tester. Calibrate gas analyzers for carbon monoxide, carbon dioxide, and if available nitrogen dioxide using either scrubbers or calibration gases.

2. Initialize computer monitoring system[5] by defining a new task specific to the test, recording initial parameters (ie. pressure levels, temperatures, pollutant concentrations, air flows, start time) and checking values for accuracy.

3. Energize air conditioner and calibrated make-up air fan.

4. Select a chamber depressurization level (-5 to -50 Pascals) that will be maintained during the test and position air flow equipment accordingly. (*For example, to achieve minor depressurization the exhaust flow created by the induced draft fan of the furnace must be partially balanced using the make-up air fan installed in the chamber wall. For 10 Pascals of depressurization and greater, the make-up air fan may need to be reversed so that it exhausts air out of the chamber.)*

5. Seal chamber access door using plastic tape to ensure a tight seal.

---

[5]Sheltair used "labmate" data acquisition equipment built by Siemetrics Ltd of Ottawa, Ontario and "Co-pilot" computer software produced by Howell and Mayhew Engineering of Edmonton, Alberta.

6. Energize furnace using an externally mounted thermostat.

7. Pressures and flows are dynamic over the first two to three minutes of the test. Operators must simultaneously adjust the make-up air fan and the chimney exhaust fan to maintain the chosen pressure across the chamber wall and a zero pressure at the flue gas collection box at the top of the test chamber. (An alternative test procedure is for the operator to maintain a positive pressure in the flue gas collection box and maintain a zero pressure across the chamber wall.)

8. The variability in air flows (averages, lows and highs) should be recorded and the time it takes to reach stable air flows. (This information will help interpret the data collected on a each furnace and may vary depending upon the size of the furnace and the air tightness of the chamber.)

9. Run the combustion gas spillage test for 20 to 30 minutes or until an equilibrium concentration of pollutants in the test chamber is reached. (At higher pressures and spill rates gas analyzers may be *overranged in 10-15 minutes of furnace operation.*)

10. At the end of test shut down furnace, terminate monitoring, and operate fans to flush out pollutants from chamber prior to next test. At the end of testing all equipment should be recelebrated and any errors found should be recorded.

3.3 Problems Encountered During Testing

Due to the dynamic nature of the heat transfer in the combustion chamber, the initial 5 - 10 minutes of test required careful and constant adjustment of make-up air fan in order to maintain stable pressures.

The air conditioner unit was set to recirculation position so as not to add or remove any air from the chamber. Unfortunately the unit was not internally sealed, and when the condenser fan was operational, some air exchange took place. An attempt was made to calculate the additional air change and it was found to be exhausting an additional 1/2 to 1 L/S. This problem resulted in more frequent adjustments of the make-up air fan, and is responsible for some of the chamber pressure fluctuations.

3.4 Results of the Lab Tests

Two current models of induced draft furnaces popular in B.C. were chosen for installation in the chamber.
Furnace A: a new 45,000 BTU Input mid efficiency appliance with an induced draft fan.
Furnace B: a new, 66,000 BTU input, mid efficiency appliance with an induced draft fan.
Calculations of spillage generation rates were based on steady state operation (ie. data collected after the flue temperatures had reached 85% of the maximum).

The two furnaces are similar to the appliances tested in the field and spilled combustion gases in the same quantity and locations. Consequently, the Chamber tests are representative of the scope and severity of problems identified in the Field Survey.

Both furnaces tested are induced draft units designed for vertical venting and co-venting with naturally aspirated DHW appliances. Within the limitation of this contract we were not able to test the second type of induced draft appliance that is designed to vent horizontally through an exterior wall. Based on the field survey findings we would expect the severity of spillage from horizontally vented Induced Draft furnaces to be equal or more severe with the exception of the John Wood DHW appliance.

The results of the lab tests were used to calculate generation rates for CO_2 spillage from furnaces A & B. These calculated values are summarized in Tables 1 & 2. The data indicates an exponential relationship between flue gas spillage and chamber depressurization. The sealing of the chimneys in both cases reduced the spillage considerably at 0 and 5 Pascals of depressurization, but at 10 Pa the difference became insignificant. The total combustion gas spillage, as a percentage of a combustion gas, increased similarly for both furnaces, with Furnace A spillage from 1 to 14%, and Furnace B spillage from 0.5 to 17%.

Table 1: Calculated Generation Rate of Carbon Dioxide for Furnace A

Chamber Depressurization (Pa)	Flue Connector		% of Total Combustion Gas Spillage (unseal)
	Unsealed ($L\ CO_2$/Min.) *	Sealed ($L\ CO_2$/Min.) *	
0	0.52	0.34	1.18
5	1.18	1.52	2.37
10	2.31	2.27	5.25
15	**	4.24	
20	6.11	6.08	13.88

*At standard pressure and temperature
**No Data Available

Table 2: Calculated Generation Rate of Carbon Dioxide for Furnace B

Chamber Depressurization (Pa)	Flue Connector		% of Total Combustion Gas Spillage (unseal)
	Unsealed (LCO_2/Min.) *	Sealed (LCO_2/Min.) *	
0	0.33	0.06	%0.51
5	0.76	0.52	%1.17
10	3.00	2.92	%4.62
15	**	4.52	
20	10.78	10.13	%16.59

*At standard pressure and temperature
**No Data Available

4.0 Feedback from Manufacturers and Regulating Groups

4.1 Feedback from Manufacturers and CGA/CGRI

In addition to discussions with representatives from the Canadian Gas Association and the Canadian Gas Research Institute, visits were made to four manufacturers: Carrier, Lennox, Duomatic Olsen, and ICG. A seminar was given to research and engineering personnel at each manufacturer. Numbers attending the seminar vary considerably from one manufacturer to the other (eg. 2, 18, 7, and 12 persons respectively). Each seminar concluded with a discussion lasting from thirty minutes to one hour. No attempt was made to document this discussion since much of the information was specific to the manufacturer's appliance, and is considered to be confidential in nature.

The seminar outline is included in an Appendix to this report, and includes a historical section on trends in Canadian Housing stock. Emphasis was given to the many factors contributing to tighter building envelopes, and increased exhaust ventilation capacity.

Manufacturer's representatives did not seem willing to engage in a detailed public discussion on potential design modifications to appliances. It is expected that such discussions will occur once everyone has a chance to absorb the information, and to meet in a confidential environment. No serious disagreement was encountered with any of the information presented by Sheltair, although there were plenty of questions for clarification, and requests for references. In general, suggestions for design modifications and new test procedures were well received.

Sheltair encouraged the manufacturer representatives to respond to the CGA request for feedback on their proposed manufacturer's test for Determining Gas Furnace Sensitivity To House Depressurization, May 24, I990. Sheltair requested that when testing the procedure, they may want to consider alternative approaches for test set-ups, such as that used by Sheltair. In the field, Sheltair found the use of a CO_2 infrared gas analyzer and indispensable tool for locating combustion gas leakage sites and obtaining a rough indication on the quantity of spillage. Although the smoke bomb method is low cost, it presents several problems that we have found inconvenient. The contamination of indoor air and the potential damage to equipment are two such problems. As a result, we encouraged manufacturers to comment but had a difficult time promoting the smoke bomb approach.

It was hoped that it would be possible to test induced draft furnaces at the manufacturers plant, in order to illustrate the various problems discussed during the seminar. However none of the facilities were appropriate for carrying out such tests.

4.2 Feedback from Regulatory and Research Bodies

Discussions with CGA, and CGRI focused on information transfer primarily, with Sheltair describing the results of work to date, and CGRI and CGA commenting on the status of relevant standards. CGRI representative John Overall suggested that it may be appropriate to use CO_2 as a trace gas for modelling concentrations of other combustion gases such as nitrogen dioxide. CGA representative Ken Bales suggested that it would be worthwhile to compare a spillage test using a smoke bomb, with the use of a CO_2 analyzer.

4.3 Insights from Meetings with Industry Representatives

Of special interest, both to CGA and to all of the manufacturers visited, was the upcoming 1992 DOE requirements for an AFUE of 78%[6] for gas furnaces. Initially it was expected that this requirement would eliminate natural draft furnaces entirely, creating a much larger market for the induced draft furnaces. Such an event would presumably lower the cost of the induced draft furnaces, since they would become a "low mark-up, large-volume" item for manufacturers. However it would appear that any wide spread use of I.D. furnaces may be significantly influenced by a new class of mid-efficiency

[6]Code of Federal Regulations, Energy #10, Part 400-499, Revised January 1, 1990, U.S. Department of Energy.

furnaces now being manufactured and marketed. This new class of furnace combines a dampered combustion air inlet, with a natural draft venting system. This approach helps to conserve heat within the furnace during the off-cycle, and may allow manufacturers to achieve 78% AFUE without induced draft.

The new class of furnace is available with spark ignition, (optional), and a vent safety shut-off switch. The new furnace with natural draft will of course be very susceptible to house depressurization, and consequently much less appropriate for Canadian houses. If the new class of furnace is successful, manufacturers of induced draft furnaces may be forced, through price competition, to make similar modifications. The result of this new innovation may be a reduced choice for Canadian houses, and possibly a requirement that only sealed combustion furnaces be installed in houses (unless houses are testified and certified as suitable for natural draft systems).

It was pointed out that the current design of induced draft furnaces is largely to make possible the co-venting of hot water heaters. Gas utilities may be reluctant to let go of this co-venting potential, because they benefit from the additional DHW load. Therefore a selection of a good cheap through-the-wall water heaters may be a prerequisite if CGA is to adopt certification tests and standards for establishing house depressurization limits. The recent release of a lower cost ID water heater by John Woods appears to satisfy this need, and may force other manufacturers to help fill this market niche.

Manufacturers emphasized that they build to minimum standards. Despite their willingness to modify designs, changes are unlikely to occur without changes to standards. It was recommended on several occasions that we talk to the Ontario Ministry of Environment, since there is an expectation that minimum energy efficiency standards will be imposed at the provincial level. These minimum levels could address house depressurization problems, if information is made available.

Commitment has been made by Canadian Gas Association (CGA) to harmonize standards with the American Gas Association (AGA). The equivalent standard to the AFUE energy certification standard in Canada is CAN-P.1-85. Research by CGA found that climatic data for Canada did not make a large difference in the ratings produced by the two standards. Based on these findings and the policy initiative to harmonize standards between the two countries, CGA chose to use the American AFUE standard. AGA has now launched a program to develop new certification tests. Consequently, AGA is influencing the both the course of technological innovation in Canada and our ability to respond to specific concerns such as combustion gas spillage of induced draft equipment.

There is some evidence that efficiency rating standards should be adapted to Canadian conditions. Although the effect of climatic differences were not found to be significant, the presence of more energy efficient tighter constructed houses and the new changes in building codes requiring a greater degree of forced ventilation makes the environment that an appliance has to operate in, significantly different between the two countries. We believe that this is clear justification for Canada to take a separate and distinct path. Is it possible for a small country such as Canada to take clearly different path and maintain the cooperation of equipment manufactures?

In this respect it may be worth looking to California as an example of a jurisdiction within the United States that has developed its own distinct standards for gas furnace appliances unlike any other State. California is now requiring low NO_x furnaces to reduce the acute air quality problems in the state, and has successfully forced technological innovation upon manufacturers. The California market is no larger than the Canadian market.

In one case a manufacturer visited during this research study was about to begin redesign of their induced draft furnace model, and was especially receptive to the suggestions made by Sheltair. They had already recognized that their furnace was "sloppy" in design. The possibility of leading the industry by producing a spillage free induced draft furnace was discussed with their design team. It is not yet clear whether this would provide a significant market advantage. In part, this will depend upon the directions taken by CGA.

All manufacturers were concerned with the reports that venting systems are extremely leaky when tested in the field, despite specifications that require sealing of joins by installers. Generally, they feel that the best solution is to require better quality venting materials. For example flexible connectors could be rolled out from the furnace. Or rigid venting pipe could be made of high temperature clear plastics, with minimal joint leakage. (The visibility of sealants through clear vent pipe should help to ensure that no spillage locations remain after installation.) Some furnace manufacturers felt that the standards for venting materials were too lenient.

In general manufacturers are appreciative of efforts to keep them informed of housing trends, and are willing to make modifications to improve the quality and performance of their appliances. Ultimately, their ability to make any significant change to the design of the appliance is influenced by the market, which at present is driven by American standards. At present the new energy efficiency standards in the U.S. ignore the performance of the house as a system. Consequently, new standards may become a major obstacle to the production of furnaces suitable for tighter Canadian houses.

5.0 Indoor Air Quality Simulations

5.1 Use of Enerpass/Contam 87

As part of a separate concurrent research project[7], Sheltair contracted Enermodal Engineering to combine their Enerpass[8] hourly thermal simulation program with the National Institute of Standards and Technology CONTAM87[9] contaminant simulation program. The result was a multipurpose simulation program referred to as Enerpass/Contam.

The main use for this new program was to predict pollutant concentrations in different locations of a typical house. The pollutant generation rates measured during the lab tests on Furnace A and B were used as inputs for the computer model.

Because two large and complex programs were required to pass data back and forth as conditions changed in the model house, the program was very slow. This imposed a restriction on the number of cases that could be investigated.

Sheltair calibrated the program to ensure that the contaminant model resulted in pollutant concentrations consistent with those measured during low level monitoring in three field research houses.

The house chosen for modelling purposes was a bungalow with a living area 123 m^2 per floor, and a full depth below grade basement. The house was located in Winnipeg, had 3 occupants, and was modeled for the month of January. The house was heated with a forced air system and was divided into only two pollutant zones - main floor and basement - with the furnace in the basement. Inter-zonal

---

[7]Demand Controlled Ventilation, by Sheltair Scientific Ltd, for CMHC Research Division, 1991

[8]Enerpass, Enermodal Engineering Ltd., Waterloo, Ontario, 1990.

[9]"Progress Toward a General Anyalytical Method for Predicting Indoor Air Pollution in Buildings," indoor air quality in Modeling, Phase III Report, by James Axley, U.S. National Institute of Standards and Technology, July, 1988

air flows had to be estimated and may be critical if pollutant emissions are strongly zone dependent. However previous field experience has shown that return air ducting in the vicinity of the furnace is leaky. Hot spillage gases rise to the ceiling, entering into the large leaks at the filter slot and around the many sheet metal joins. Consequently pollutants released into the furnace room are quickly distributed throughout the house.

The operation cycle of the furnace was determined by the program based on the heat loss of the envelope and the outdoor temperature. The size of the equivalent leakage area (ELA) in the house and the flow rate from an operating exhaust fan are the two dependent variables that determine the concentration of pollutants from a spilling furnace.

The house was assumed to have a continuous exhaust fan flow rate, varying between 32 L/s and 75 L/s. The flow rates represent typical flows that have been measured for bathroom fans and a combination of bathroom fans and small range hood fans[10]. House leakage areas of 150 cm^2 to 300 cm^2 were chosen, representing typically ELA values for new houses in Winnipeg[11]. These flow rates combined with the ELA result in levels of house depressurization ranging between 0 to 20 Pascals.

The generation of pollutants from the furnace was extracted from Table 2 "Calculated generation rate of Carbon Dioxide for Furnace B" with the furnace and vent connector installed without extra sealing of joins. Furnace B was the larger of the two furnaces tested and more closely matches the heating load of the modelled house.

The model assumes two sources of carbon dioxide (CO_2) in the house - the occupants and the furnace. A typical schedule for occupancy was input into the program and was used to determine the contribution of CO_2 from

---

[10]The Canadian Duct and Chimney Survey, by Sheltair Scientific Ltd, for CMHC Research Division, 1989

[11]Ventilation and Airtightness in New Detached Canadian Housing, Hamlin et. al., CMHC Research Division, May, 1990

occupants, as shown in Figure 5. For both nitrogen dioxide (NO2) and carbon monoxide (CO), the furnace was assumed to be the only source. NO_2 and CO were calculated as a multiple of the amount of CO_2 released by the furnace, (with no consideration for the possible re-ingestion of combustion gases by the burner).

CO_2 was assumed to be a tracer for NO_2 and CO. A ratio had to be determined between the 3 gases. Rather than using a formula to calculate levels of NO_2 and CO, a ratio was obtained from collections of published field data on measured emission rates from a range of gas appliances.[12]

Two sources of ventilation combine to create the total air change for the house. Natural ventilation, caused by the temperature difference across the house envelope, was assumed to be 0.1 Air Changes per Hour (ACH) in all cases[13]. Forced ventilation supplements this rate, and varies depending on the flow of exhaust fans. The total ventilation rate was less than the sum of the natural and forced rates. (It is estimated as the square root of the sum of the squares.) The net values ranged from 0.26 to 0.78 ACH.

---

[12] This information was obtained from a text on **Indoor Air Pollution** written by Wadden and Scheff, 1983.

[13] 20% of new houses have air change rates less than. 1 ACH

Figure 4: Occupancy Schedule & Corresponding Metabolic CO_2 Generation for a Model House

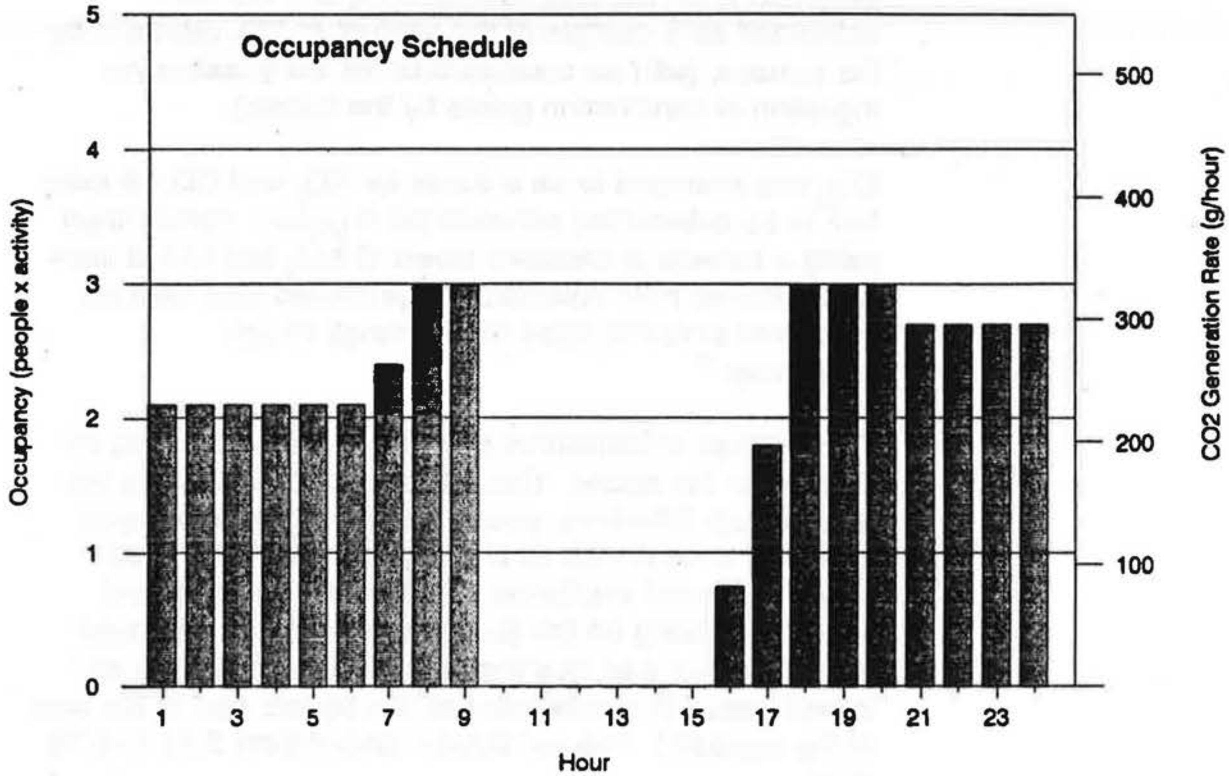
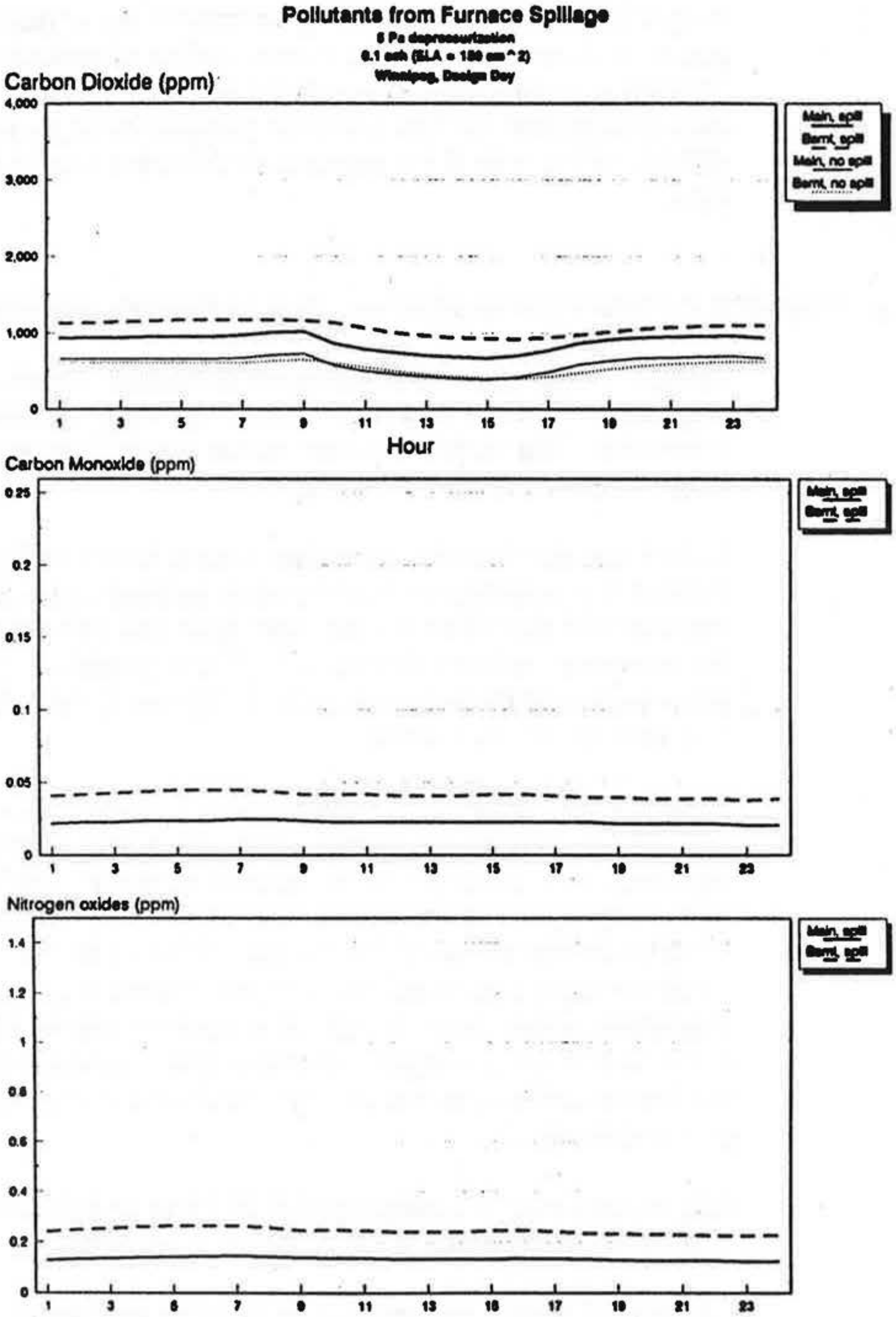


Figure 5: Pollutant Concentrations from Furnace Spillage at 5 Pa House Depressurization



The house size, furnace size, ventilation rate and occupancy were all based on average or typical conditions for Canadian Housing and should represent what may frequently occur in real life.

A special simulation was run to determine the impact of a powerful exhaust fan on the concentration of pollutants. The fan was assumed to create 20 Pascals of house depressurization for two one-hour periods (8AM to 9AM and 5PM to 6PM), with 5 Pa depressurization the rest of the time.

5.2 Predicted Pollutant Concentrations due to Furnace Spillage

Tables and graphs of the computer simulation results have been located at the end of this report for reading and reference. The numeric results of the simulations are summarized in Tables 3 through 5.

With 3 occupants in the modelled house, levels of CO_2 without any contribution from furnace spillage reach a maximum of 802 PPM on the main floor and 704 PPM in the basement with an APH of 0.3. For a graphical presentation of these results refer to Figure 5, main floor no spill and basement no spill.

Pollutant concentrations including contributions from the furnace, are plotted in Figures 5 through 9 (these graphs represent only a sample of the total simulations that were run). CO_2 ranged from a maximum of 1177 PPM at 5 Pa of continuous depressurization, to 3570 PPM at 20 Pa of continuous depressurization. The maximums only dropped marginally when house ELA's were increased from 150 cm^2 to 300 cm^2 suggesting that house depressurization, not house leakage, is the primary determinant of pollutant concentrations.

NO_2 ranged from a maximum of 0.25 PPM at 5 Pa of depressurization to 1.4 PPM at 20 Pa of depressurization.

CO ranged from a maximum of 0.04 PPM at 5 Pa of depressurization, to 0.23 PPM at 20 Pascals of depressurization.

Because the simulations were run over several days, the average and the maximum concentrations were relatively close. The house approaches an equilibrium state within several hours.

Figure 5 shows the concentration of pollutants over a 24 hour period after several days of operation where the house has reached a relatively stable condition. In this case the house is continuously depressurized to 5 Pa and the ELA of the house is 150 cm^2. The house has a combined air change rate of .33 ACH. Outdoor temperatures range from a low of -35.6 C to a high of -23.9 C with a trend of rising temperatures over the 24 hour period. During the middle of the day when occupants are away at work and school the total CO_2 levels decrease and the NO_2 and CO levels remain almost constant.

Figure 6 and 7 show similar results, but for house depressurization of 10 and 20 Pa respectively. Figures 8 and 9 show limited impact from intermittent operation of a powerful exhaust fan.

5.3 Insights from Air Quality Simulations

It is not possible in this report to provide an exhaustive review of the air quality implications of spilling furnaces. We have chosen instead to reference a recent paper produced as a cooperative effort by a number of countries under the International Energy Agency (IEA).[14] The paper reviews the existing air quality standards for CO_2, NO_2, and CO. Tables 6 to 8 present the threshold levels for indoor CO_2, NO_2, and CO in various western countries, (as summarized from the IEA). These levels provide a basis for interpreting the concentrations of the gases reached in the simulations of a house subjected to spillage from furnaces.

Although the toxicity level of CO_2 is over 50,000 PPM, there is a general consensus that levels of CO_2 in the 1000 to 1500 PPM range are a maximum for indoor environments. (Refer to Table 6) Some countries distinguish between

[14]Demand Controlled Ventilation, **State of the Art Review**, I.E.A., June 1989.

CO_2 produced by metabolism (used as an indicator of odours caused by humans) and CO_2 produced by other processes (such as fermentation) Table 6 lists the Canadian Health Guideline for CO_2, not as an indicator for body order, at 3500 PPM. At this time the levels of CO_2 detected in the simulations appear to represent a concern only in terms of comfort, and not health. The extent of possible discomfort would vary with the sensitivity of occupants.

NO_2 appears to be the major health concern from spilling furnaces. Canada's guideline of 0.052 PPM for NO_2 levels in homes is closely in line with other countries standards. The text book Indoor Air Pollution, by Wadden and Scheff, summarizes studies done on the health effects of Nitrogen Dioxide. Many have shown a link between the use of gas cooking ranges and acute respiratory disease in young children. Adults are not effected. A table from the text titled "Effects of exposure to Nitrogen Dioxide in the Home on the incidence of Acute Respiratory Disease in Epidemiology Studies involving Gas Stoves" is included as a reference in the Appendix. Of particular interest is a 1980 study by Speizer et al. including 8120 children which shows a significant relationship with indoor 24 hour average levels of NO_2 between .02 and .06 PPM.

The 0.25 PPM concentrations for NO_2 in the model house, at 5 Pa of continuous house depressurization, is far in excess of the levels recommended by Health and Welfare Canada. Even without house depressurization the spillage from a mid efficiency furnace could cause NO_2 levels to exceed this standard.

The natural base level of CO is 0.044 - 0.087 ppm. Levels can reach 40 ppm with high traffic on downtown streets. The acceptable indoor concentration for Carbon Monoxide is in the 9 ppm range. Only German data reports a much lower concentration Guideline of 1 - 2 ppm. The computer simulations showed that concentrations never exceeded 0.1 ppm. Consequently, the simulations do not raise any concern about CO, (although this analysis did not consider poorly tuned furnaces or furnaces suffering from a lack of proper maintenance).

6.0 Redefining the Issues

6.1 The Importance of Consumer Confidence and Comfort

Regardless of whether furnace spillage constitutes a significant health hazard, it is difficult to justify if the effect is to loose the consumer's confidence and "peace of mind". Any amount of spillage form a furnace is probably unacceptable from a public relations perspective. Rationalizing a "little bit" of spillage to mothers with children is probably an impossible task, whatever our current knowledge on acute and long term health effects.

Combustion gas spillage may also result in odours or higher humidity, leading to occupant discomfort. The comfort issue is often overlooked once a concentration of a pollutant has been shown not to be a health concern. However comfort in an indoor environment is now recognized to be extremely important to the new house buying market. So the key issue for the gas industry may not be health effects, but consumer confidence and comfort. In this context, changes to furnaces are probably worthwhile, especially since eliminating spillage requires slight, low cost design modifications which some manufactures have already initiated.

6.2 The House As A System

The Department of Energy DOE in the US will be enforcing the Energy Efficiency Act which requires that appliances meet an AFUE of 78%. The Provinces of Ontario and B.C. are enacting their own energy efficiency acts. The effect of these moves will be to greatly reduce the market for conventionally aspirated appliances. The base model furnace will likely become the current mid-efficiency model. Will this move towards energy efficiency actually achieve its objective?

With current codes and technology the answer is negative. It is our viewpoint that an energy efficient appliance should be defined as an appliance that burns fuel efficiently **and is designed to operate in an energy efficient house.** If the appliance burns its fuel efficiently but can only be operated safely if a window sized hole is open to the outdoors how can we possibly call this appliance energy efficient or suited to an energy conscious building industry. If the appliance is spilling under normal operating conditions, the house may need to be ventilated at a higher rate than normal. This could be a further energy penalty to the house.

A better objective for energy efficiency acts would be to require that the gas codes eliminate entirely the need for combustion/replacement air. Combustion air ducts give a false sense of safety since they are ineffective at improving the operational safety of mid efficiency gas appliances. Their continued use is a function of looking at the appliance in isolation from the rest of the house, and ignores the systems approach.

There are 3 major cost penalties to the inclusion of combustion air ducts in energy efficient houses. The costs are listed below:

Costs of Combustion Air Ducts	
1.	Installation Costs (approximately $60/hour)
2.	Envelope Air sealing (a 125 cm^2 opening now costs builders about $92 to air seal - an expense that is completely undermined by the combustion air duct)
3.	Tempering the Combustion Air (with a continuous operating furnace blower, and coil in B.C., extra heating costs would be $70 annually, or $1750.00 over a 25 year period).

Despite these substantial costs, there are no real benefits resulting from the combustion air ducts. Even houses built to the airtight specifications of the R2000 program have sufficient envelope leakage to satisfy the requirements of combustion air, and draft, for gas appliances. (The average leakage area of an R2000 house is 54 in^2 - or an 8 inch round duct). The installation of a combustion air duct does not guarantee that air will be available for the gas appliance, nor does it guarantee that depressurization levels won't exceed tolerances.

A more substantial threat to the proper operation of forced air furnaces is the imbalance in pressures within the house that can be caused by leaky return air ducting and a tight furnace room. The furnace blower draws air through the leaky ductwork and causes the room to be depressurized relative to the rest of the house, and to the outdoors.

To ensure that furnaces are not affected by the depressurization caused by exhaust fans or furnace blowers, the industry has three options.

1. The first option is to encourage installers to build and install balanced ventilation systems, with tight ducting, and to require a large relief opening between the furnace room and the house. (A spill grill in the supply air plenum is no guarantee that an imbalance in pressures will not occur.) If the furnace room is properly connected with the rest of the house, the entire ELA of the house becomes available, ensuring sufficient combustion air to supply the furnace.

2. A second option is to install only sealed combustion appliances in energy efficient houses.

3. A third option is to redesign the mid-efficiency appliances so they can operate against all reasonable levels of house depressurization, - for example, up to 50 Pascals.

In the long run the last option is probably the least costly and easiest to administer. Field testing of appliances indicted that induced draft blowers in chimneys will not back up, even at 50 Pascals of house depressurization. Spillage occurs only as a result of leaks down stream of the blower, the fan axle holes, fan housing, and vent collar - all of which can be designed to be gas tight.

The combustion air duct has long been considered a safety net, - a role to which it is unsuited. The gas industry has no control over whether a builder or homeowner installs a powerful direct vent exhaust fan in the kitchen of a tight house, or whether the duct work is tight or leaky. Installing the furnace to the letter of the code will not protect the furnace and chimney from interacting with the exhaust fan or blower.

Even a large 200 L/s exhaust fan is not capable of depressurizing tight houses more than 50 Pascals. It is also unlikely that anyone could inadvertently reduce the leakage area of a furnace room to the point where duct leakage could depressurize the room to 50 Pascals. The task of air sealing such rooms is simply too difficult.

Why do we identify 50 Pascals a critical number? This is probably the maximum negative pressure the house envelope should experience to maintain the integrity of an air vapour barrier.

A huge benefit to the gas industry in taking these steps is that appliances would become "in-step" with housing trends occurring across the country. We are moving towards a future where all houses will be energy efficient, even low-end housing.

This is why sealed combustion condensing gas furnaces must not be the only appliances suitable for operation in an energy efficient house. The payback period for these appliances is extremely long once heating loads are drastically reduced. An analogy can be made between the inappropriateness of sealed combustion appliances, and the rejection of active solar heating systems in the 1980s. The housing industry has already learned that it is far more cost effective over the long term to reduce the heating load of a house through higher insulation levels, air sealing, and heat recovery ventilation, than to sink money into a more efficient heating appliance.

7.0 Conclusions

1. Field Tests

- The majority of induced draft appliances tested in the field were found to spill combustion gases under normal operating conditions.

- The quantity of spillage increases exponentially as house depressurization increases from 0 to 20 Pascals.

- The percentage of combustion gas that spills indoors is greater for appliances with larger fuel input rates.

- Combustion gases spill down stream of the induced draft blower, at the fan axle hole, joins in the blower housing, the connection between the furnace and the vent connector, and at joins in the vent connector.

- The location and quantity of leakage varies by appliance manufacturer and installation practice.

- Induced Draft boilers and some DHW appliances share the same problems identified with induced draft furnaces.

2. Lab Tests

- An airtight test chamber can be used to accurately calculate the generation rates of CO_2 caused by spillage from two models of mid-efficiency furnaces.

- The generation rate of CO_2 at 0 Pascals of chamber depressurization was 0.52 Litres/minute for Furnace A, and 0.34 minutes for Furnace B

- The generation rate at 20 Pa of chamber depressurization was 6.11 L/min for Furnace A, and 10.78 L/min for Furnace B. This quantity of spillage represents 14% and 17% of the total combustion gas for each of these furnaces. (or 17% of the combustion gases),

- The impact on generation rates from sealing joins of the vent connector is marginal.

3. Computer Simulations

- A typical new house can be modelled using a combined Enerpass/Contam computer simulation program.

- Predicted levels of CO_2 with without any contribution from furnace spillage reach a maximum of 802 ppm on the main floor and 704 ppm in the basement (based on 3 person occupancy).

- With contribution from furnace spillage, CO_2 levels range from a maximum of 1177 ppm at 5 Pa of depressurization to a maximum of 3570 PPM at 20 Pa of depressurization. These levels represent a possible concern for occupant comfort, and would require increased house ventilation.[15]

- NO_2 levels range from 0.25 ppm at 5 Pa to 1.4 ppm at 20 Pa. These levels exceed Canadian Health and Welfare Guidelines for indoor air quality, as well as exceeding many foreign standards. Average NO_2 levels also exceed concentrations measured by other researchers, in houses where a link has been made between acute respiratory disease in children, and gas cooking.[16]

---

[15]These estimates are conservative because they do not take into account the contribution from an induced draft DHW appliance.

[16]These estimates are conservative because they do not take into account the contribution from an induced draft DHW appliance.

- CO never exceeded 0.23 PPM and is not likely to be a health or comfort concern as long as furnaces are properly maintained.[17]

3. Visits to Manufacturers

- During the seminars, manufacturers representives agreed that eliminating spillage would require low cost, relatively simple design changes to the induced draft fan housing, and possible changes to vent connector design.

4. Recommendations

- For reasons of health, comfort and consumer confidence it is imperative that the gas industry modify the design of mid-efficiency furnaces to eliminate spillage potential.

- An energy efficient appliance should be defined as an appliance that burns fuel efficiently **and is designed to operate in an energy efficient house.**

- Condensing gas furnaces with sealed combustion are too expensive for low-end housing, and will frequently be impossible to justify on energy payback analysis since new energy efficiency codes will apply to all segments of the housing market, it is vital that mid-efficiency appliances become suitable for use in energy efficient houses.

- Mid-efficient appliances should be capable of operating under house depressurization levels that maintain the integrity of the envelope, with no measurable combustion gas spillage.

---

[17] These estimates are conservative because they do not take into account the contribution from an induced draft DHW appliance.

- Code requirements for combustion/replacement air ducts for mid-efficiency furnaces should be eliminated. A combustion air supply gives a false sense of safety, it is ineffective at improving the operational safety of mid efficiency gas appliances, and it imposes 3 major cost penalties on builders and homeowners.

- CGA should make changes to B149 and draft a manufactures test procedure for energy efficient appliances that is more comprehensive than the DOE tests. We recommend that such a test procedure include the use of a test chamber similar to the one designed and constructed for this research because of its ease of construction, low cost, and air tightness characteristics.

- Gas Safety authorities and building inspectors have been lax in enforcing manufacturers requirements for the sealing of vent connectors. It is recommended that an industry bulletin be drawn up to alert inspectors to the importance of sealing flue connectors.

Table 3: Results of Simulation For A House ELA = 150cm²

FURNACE SPILLAGE						Unsealed						Sealed					
January 15th	0.10 air change natural																
Winnipeg	0.33 air change total					Depressurization (Pa):						Depressurization (Pa):					
	(53L/s exhaust ventilation)					5		10		20		5		10		20	
Average	-30.2	21.0	15.2	31.3	6.7	881	1,074	1,153	1,564	2,080	3,245	961	1,219	1,126	1,515	2,071	3,232
StdDev	3.4	0.0	0.4	3.0	0.6	109	89	108	89	141	202	112	94	107	88	139	200
Min	-35.6	21.0	14.8	26.5	5.7	670	925	955	1,450	1,870	3,040	746	1,064	928	1,401	1,860	3,020
Max	-23.9	21.0	15.9	36.7	7.9	1,025	1,177	1,304	1,680	2,319	3,570	1,107	1,327	1,277	1,629	2,309	3,550
HOUR	Tout (C)	Tmain (C)	Tbsmt (C)	Furnmain (MJ/h)	Furnbsmt (MJ/h)	CO2main (ppm)	CO2bsmt (ppm)	CO2main (ppm)	CO2bsmt (ppm)	CO2main (ppm)	CO2bsmt (ppm)	CO2main (ppm)	CO2bsmt (ppm)	CO2main (ppm)	CO2bsmt (ppm)	CO2main (ppm)	CO2bsmt (ppm)
1	-31.7	21.0	15.9	35.0	7.5	933	1,129	1,187	1,610	2,069	3,247	1,012	1,275	1,158	1,560	2,060	3,236
2	-32.2	21.0	15.9	35.4	7.6	938	1,140	1,204	1,630	2,120	3,344	1,022	1,294	1,174	1,580	2,120	3,334
3	-33.3	21.0	15.8	36.0	7.7	944	1,152	1,217	1,650	2,180	3,443	1,032	1,314	1,187	1,600	2,170	3,433
4	-34.4	21.0	15.7	36.7	7.9	951	1,164	1,231	1,680	2,230	3,542	1,041	1,327	1,200	1,629	2,221	3,531
5	-33.3	21.0	15.6	36.3	7.8	956	1,174	1,237	1,680	2,259	3,570	1,041	1,326	1,209	1,629	2,240	3,550
6	-32.8	21.0	15.6	35.9	7.7	957	1,174	1,237	1,679	2,259	3,569	1,041	1,326	1,209	1,629	2,240	3,549
7	-33.3	21.0	15.5	34.3	7.4	975	1,173	1,255	1,678	2,279	3,564	1,059	1,326	1,227	1,628	2,260	3,544
8	-34.4	21.0	15.4	32.5	7.0	1,013	1,177	1,292	1,678	2,319	3,552	1,097	1,326	1,264	1,628	2,309	3,533
9	-35.6	21.0	15.1	29.3	6.3	1,025	1,171	1,304	1,674	2,313	3,457	1,107	1,315	1,277	1,624	2,303	3,438
10	-34.4	21.0	15.0	30.2	6.5	863	1,135	1,144	1,640	2,122	3,357	943	1,279	1,117	1,590	2,111	3,337
11	-31.7	21.0	15.0	27.4	5.9	788	1,067	1,060	1,539	2,026	3,242	867	1,208	1,036	1,499	2,015	3,222
12	-30.6	21.0	14.9	26.5	5.7	740	1,004	997	1,450	1,929	3,111	817	1,142	974	1,410	1,919	3,101
13	-29.4	21.0	15.0	28.7	6.2	706	967	966	1,451	1,870	3,040	783	1,104	940	1,402	1,861	3,030
14	-28.9	21.0	15.0	28.8	6.2	684	937	955	1,451	1,870	3,040	760	1,074	928	1,401	1,860	3,020
15	-30.0	21.0	15.0	30.8	6.6	670	927	955	1,453	1,871	3,047	746	1,064	928	1,404	1,861	3,027
16	-28.3	21.0	15.0	30.7	6.6	702	925	992	1,455	1,877	3,047	779	1,066	965	1,405	1,867	3,027
17	-28.9	21.0	15.0	29.4	6.3	770	938	1,061	1,456	1,940	3,045	848	1,078	1,033	1,406	1,929	3,026
18	-27.8	21.0	14.9	28.9	6.2	865	972	1,148	1,460	2,030	3,048	942	1,111	1,121	1,410	2,020	3,029
19	-27.2	21.0	14.9	30.0	6.4	913	1,018	1,192	1,520	2,060	3,100	990	1,158	1,166	1,470	2,060	3,100
20	-26.7	21.0	14.9	30.0	6.4	944	1,056	1,217	1,540	2,060	3,100	1,021	1,196	1,191	1,490	2,060	3,100
21	-26.1	21.0	14.8	29.7	6.4	950	1,080	1,214	1,539	2,057	3,099	1,028	1,219	1,187	1,489	2,057	3,098
22	-25.0	21.0	14.8	29.4	6.3	959	1,093	1,214	1,539	2,057	3,098	1,036	1,232	1,186	1,489	2,057	3,097
23	-24.4	21.0	14.8	29.0	6.2	964	1,103	1,214	1,538	2,057	3,096	1,041	1,242	1,186	1,488	2,057	3,096
24	-23.9	21.0	14.8	30.6	6.6	937	1,108	1,180	1,538	2,054	3,120	1,014	1,247	1,152	1,489	2,053	3,110

Table 4: Results of Simulation For House with ELA's Of 200 cm² and 300 cm²

FURNACE SPILLAGE		ELA = 200 cm2						ELA = 300 cm2					
Exhaust Fan:		32 L/s		50.0 L/s		78 L/s		47 L/s		75 L/s		117 L/s	
Total air change:		0.26 ach		0.34 ach		0.48 ach		0.45 ach		0.57 ach		0.78 ach	
January 15th		Depressurization (Pa):						Depressurization (Pa):					
Winnipeg		5		10		20		5		10		20	
Average	-30.2	989	1,120	1,119	1,536	1,673	3,205	731	909	851	1,335	1,314	3,190
StdDev	3.4	134	99	115	85	89	119	105	71	90	55	63	109
Min	-35.6	725	943	911	1,410	1,510	3,020	540	783	691	1,238	1,192	3,049
Max	-23.9	1,146	1,225	1,249	1,630	1,806	3,409	872	1,013	963	1,420	1,391	3,360
HOUR	Tout (C)	CO2main (ppm)	CO2bsmt (ppm)	CO2main (ppm)	CO2bsmt (ppm)	CO2main (ppm)	CO2bsmt (ppm)	CO2main (ppm)	CO2bsmt (ppm)	CO2main (ppm)	CO2bsmt (ppm)	CO2main (ppm)	CO2bsmt (ppm)
1	-31.7	1,039	1,172	1,137	1,569	1,667	3,171	753	937	889	1,325	1,274	3,065
2	-32.2	1,039	1,183	1,151	1,580	1,667	3,171	753	941	889	1,325	1,285	3,121
3	-33.3	1,049	1,193	1,165	1,609	1,681	3,269	753	941	889	1,325	1,312	3,220
4	-34.4	1,055	1,204	1,179	1,630	1,720	3,339	753	941	889	1,325	1,339	3,288
5	-33.3	1,055	1,209	1,180	1,629	1,720	3,356	753	941	889	1,325	1,340	3,315
6	-32.8	1,058	1,210	1,182	1,629	1,749	3,404	753	941	879	1,345	1,360	3,360
7	-33.3	1,077	1,211	1,200	1,628	1,752	3,409	770	951	879	1,345	1,378	3,357
8	-34.4	1,113	1,211	1,233	1,627	1,800	3,405	802	957	879	1,345	1,378	3,357
9	-35.6	1,134	1,208	1,249	1,625	1,806	3,340	820	955	901	1,348	1,391	3,337
10	-34.4	968	1,176	1,093	1,590	1,665	3,280	673	928	778	1,344	1,358	3,319
11	-31.7	882	1,106	1,014	1,499	1,590	3,172	616	872	735	1,295	1,331	3,277
12	-30.6	826	1,042	957	1,420	1,550	3,074	584	827	715	1,260	1,280	3,178
13	-29.4	782	1,002	924	1,412	1,521	3,050	561	803	701	1,250	1,253	3,143
14	-28.9	748	963	911	1,410	1,510	3,020	546	783	691	1,238	1,204	3,054
15	-30.0	725	943	911	1,413	1,511	3,027	540	783	691	1,248	1,192	3,053
16	-28.3	775	947	966	1,417	1,560	3,100	599	801	756	1,290	1,192	3,053
17	-28.9	838	959	1,023	1,417	1,599	3,093	653	816	803	1,297	1,206	3,050
18	-27.8	956	999	1,120	1,440	1,690	3,099	757	858	894	1,330	1,292	3,049
19	-27.2	1,025	1,059	1,178	1,520	1,720	3,160	808	907	933	1,380	1,341	3,103
20	-26.7	1,082	1,115	1,222	1,560	1,740	3,200	849	952	963	1,420	1,370	3,153
21	-26.1	1,107	1,158	1,228	1,569	1,737	3,198	859	983	961	1,419	1,369	3,180
22	-25.0	1,126	1,186	1,228	1,568	1,737	3,196	860	994	952	1,417	1,367	3,174
23	-24.4	1,146	1,206	1,228	1,568	1,737	3,195	872	1,004	953	1,418	1,368	3,176
24	-23.9	1,126	1,225	1,201	1,579	1,732	3,199	848	1,013	927	1,418	1,364	3,189

Table 5: Results of Simulation with A Large Exhaust Fan Operating Twice Daily

FURNACE SPILLAGE						Unsealed			
January 15th	0.10 air change natural								
Winnipeg	0.32 air change total					Depressurization (Pa):			
	(53L/s exhaust ventilation)					5		2, 20 Pa spikes	
Average	-30.2	21.0	15.2	31.3	6.7	881	1,074	893	1,113
StdDev	3.4	0.0	0.4	3.0	0.6	109	89	130	127
Min	-35.6	21.0	14.8	26.5	5.7	670	925	648	882
Max	-23.9	21.0	15.9	36.7	7.9	1,025	1,177	1,066	1,368
HOUR	Tout (C)	Tmain (C)	Tbsmt (C)	Furnmain (MJ/h)	Furnbsmt (MJ/h)	CO2main (ppm)	CO2bsmt (ppm)	CO2main (ppm)	CO2bsmt (ppm)
1	-31.7	21.0	15.9	35.0	7.5	933	1,129	945	1,143
2	-32.2	21.0	15.9	35.4	7.6	938	1,140	938	1,138
3	-33.3	21.0	15.8	36.0	7.7	944	1,152	938	1,137
4	-34.4	21.0	15.7	36.7	7.9	951	1,164	938	1,143
5	-33.3	21.0	15.6	36.3	7.8	956	1,174	938	1,143
6	-32.8	21.0	15.6	35.9	7.7	957	1,174	938	1,143
7	-33.3	21.0	15.5	34.3	7.4	975	1,173	955	1,153
8	-34.4	21.0	15.4	32.5	7.0	1,013	1,177	955	1,153
9	-35.6	21.0	15.1	29.3	6.3	1,025	1,171	1,004	1,197
10	-34.4	21.0	15.0	30.2	6.5	863	1,135	855	1,136
11	-31.7	21.0	15.0	27.4	5.9	788	1,067	782	1,069
12	-30.6	21.0	14.9	26.5	5.7	740	1,004	735	1,004
13	-29.4	21.0	15.0	28.7	6.2	706	967	696	944
14	-28.9	21.0	15.0	28.8	6.2	684	937	668	911
15	-30.0	21.0	15.0	30.8	6.6	670	927	648	884
16	-28.3	21.0	15.0	30.7	6.6	702	925	677	882
17	-28.9	21.0	15.0	29.4	6.3	770	938	744	900
18	-27.8	21.0	14.9	28.9	6.2	865	972	935	1,368
19	-27.2	21.0	14.9	30.0	6.4	913	1,018	1,048	1,300
20	-26.7	21.0	14.9	30.0	6.4	944	1,056	1,066	1,246
21	-26.1	21.0	14.8	29.7	6.4	950	1,080	1,042	1,213
22	-25.0	21.0	14.8	29.4	6.3	959	1,093	1,022	1,189
23	-24.4	21.0	14.8	29.0	6.2	964	1,103	1,011	1,169
24	-23.9	21.0	14.8	30.6	6.6	937	1,108	964	1,139

Figure 6: Pollutant Concentration at 10 Pa House Depressurization

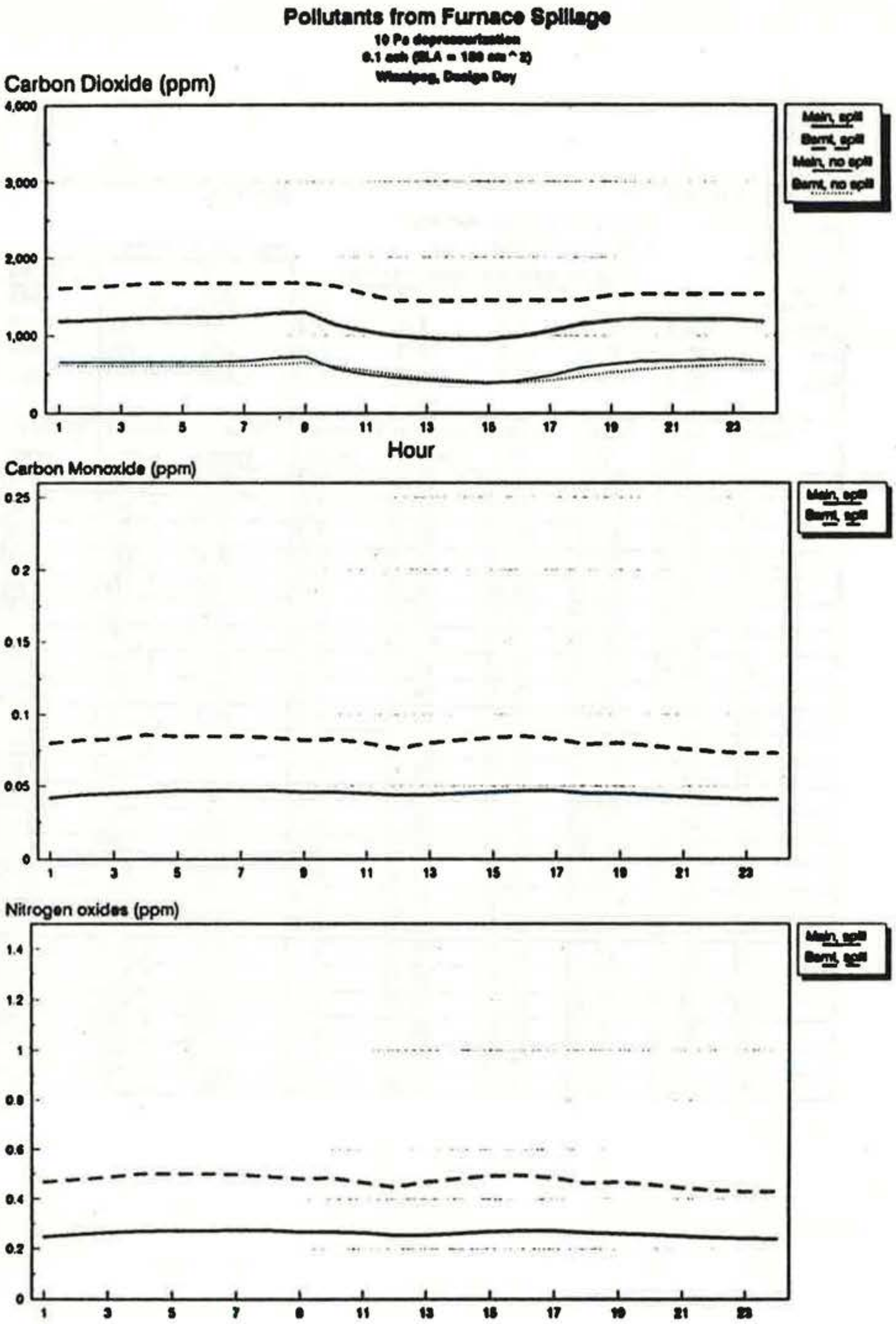


Figure 7: Pollutant Concentrations at 20 Pa House Depressurization

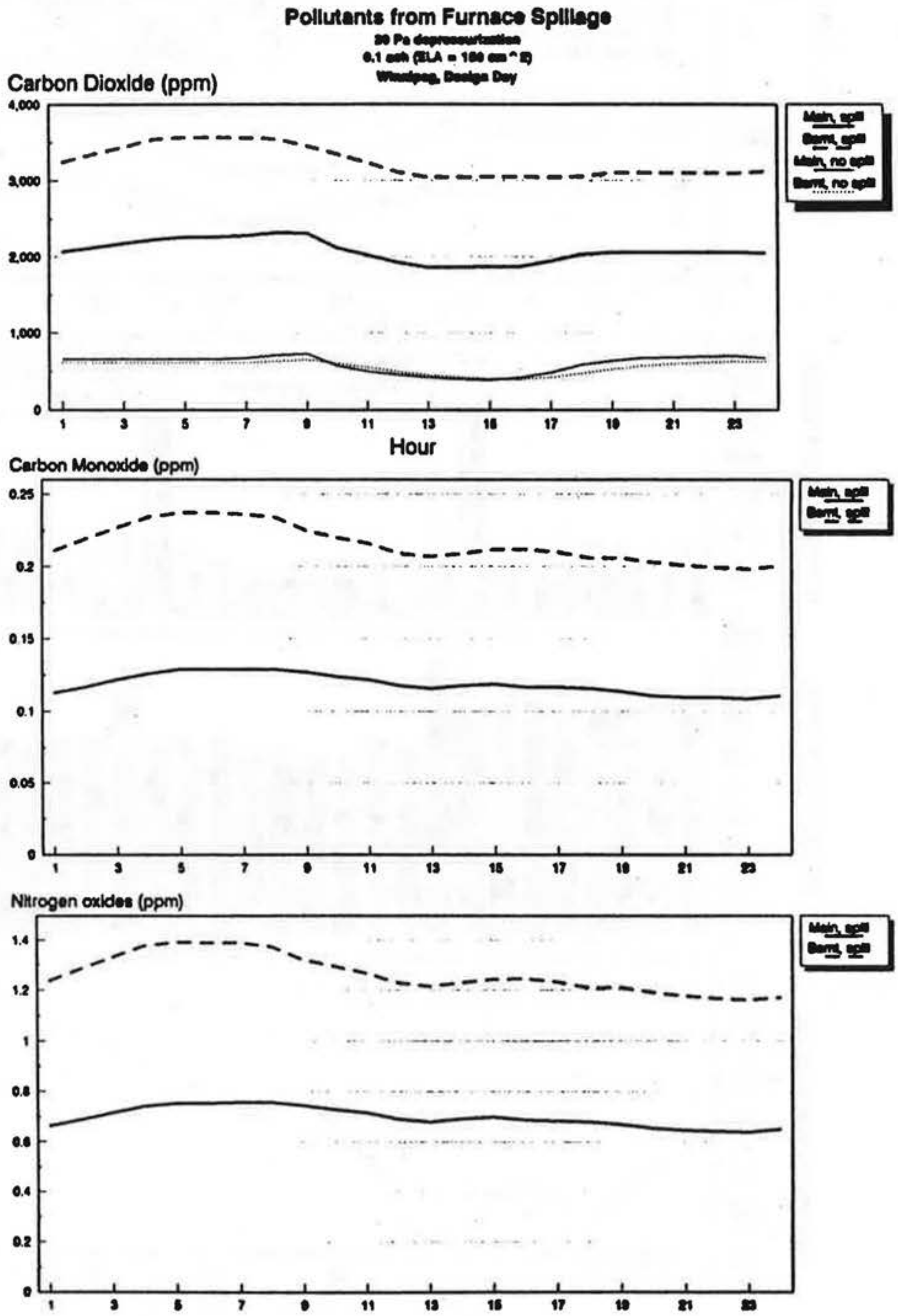


Figure 8: Impact of High Capacity Exhaust Fan on CO_2

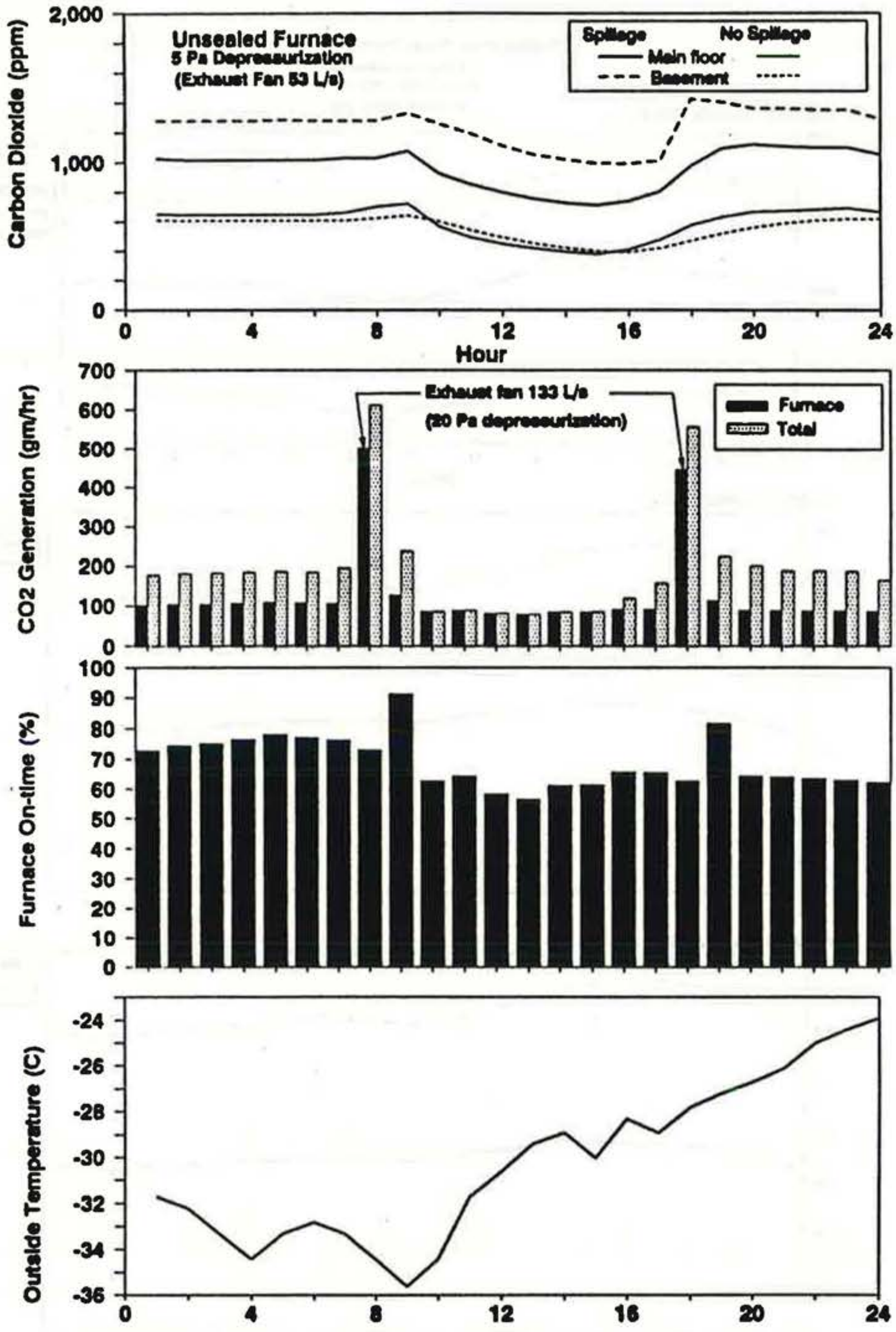


Figure 9: Pollutant Concentrations with Two 20 Pa Spikes

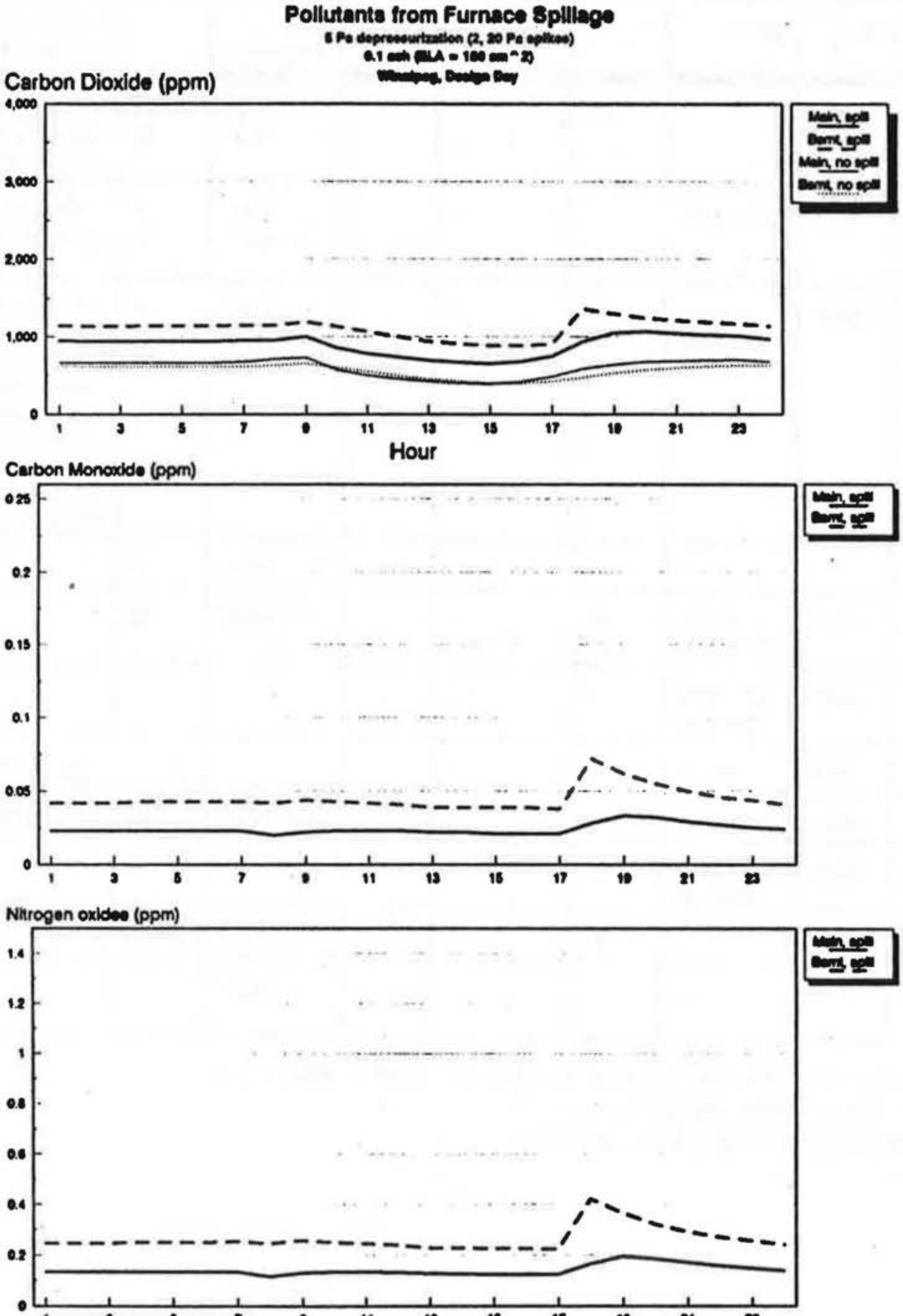


Table 6: Threshold Levels for Carbon Dioxide CO_2 in Buildings in Different Countries

Concentration Level	MAC	Peak limit	Ref.	ME-value	Ref.	AIC	Ref.	Remarks
Country	ppm	ppm		ppm		ppm (absolute)		1 ppm = 1.806 mg/m³ (at 1 bar, 293 K)
Canada	5000 -	-	21	-		3500 1000	22 20	CO_2 level not used as indicator for body odour Produced by metabolism
Germany	5000	2 x MAC	8	-		1000 1500 max.	24 24	Pettankofar-value used to establish necessary AIC-air flow rates
Finland	5000	5000 (15 min)	1	-		2500	35	AIC: of which 1500 ppm is produced by metabolism If the outdoor air flows are controlled based on the carbon dioxide content of the indoor air, a maximum set point of 800 ppm may be used
Italy	-	-		-		1500	2	
The Netherlands	5000	15000 short time	40 41	-		1000-1500	42	
Norway	5000	MAC+25% (15 min)	3	-		-		
Sweedan	5000	10000	4	-		-		supply air 1/10 of MAC /5/
Switzerland	5000	-	6	-		1000-1500	30	proposed according /30/
U.K.	5000	15000 (10 min)	17	-		-		
U.S.A.	5000	-	21	-		1000	20	
Columbus Spacestation	-	-	-	-		4000	19	

MAC =Maximum Allowable Concentration at the work space 8 h/d
ME-value =Maximum Environmental Value
AIC =Acceptable Indoor Concentration

Table 7: Maximum Concentration Level for Carbon Monoxide (CO) in Buildings in Different Countries

Concentration Level	MAC	Peak limit	Ref.	ME-value	Ref.	AIC	Ref.	Remarks
Country	ppm	ppm		ppm		ppm (absolute)		1 ppm = 1.888 mg/m³ (at 1 bar, 293 K)
Canada	50	400 (15 min)	21	-		9	20.22	
Germany	30	2 x MAC (30 min) average	8	43 (1/2 h) 8 (24 h) 8 (1 year)	9	1-2 9 living rooms 18 kitchen (3 h)	35	
Finland	30	75 (15 min)	1	-		8.7 daily av. 26 hourly av.	35	
Italy	30	-	2	-		-		
The Netherlands	25	125 (15 min)	40	-		35 (1 h) 8.7 (8 h)	43	
Norway	35	+ 50% (15 min)	3	-		-		
Sweeden	35	100	4	-		12	10	supply air 1/10 of MAC /5/
Switzerland	30	-	6	7 (24 h) average	16 37	-	-	ME-value: this value ought to be exceeded only once a year
U.K.	50	400 (10 min)	17	-		-		
U.S.A.	50	400 (15 min)	20			9	20	
WHO		87(15 min) 53(30 min) 26(1 hour) 9(8 hours)	10	-		-		Guideline value; based on effects other than cancer or odour/annoyance
Airplanes	50	-	18	-		-		

MAC =Maximum Allowable Concentration at the work space 8 h/d
ME-value =Maximum Environmental Value
AIC =Acceptable Indoor Concentration

Table 8: Maximum Concentration Level for Nitrogen Dioxide (NO_2) in Buildings in Different Countries

Concentration Level	MAC	Peak limit	Ref.	ME-value	Ref.	AIC	Ref.	Remarks
Country	ppm	ppm		ppm		ppm (absolute)		1 ppm = 1.149 mg/m³ (at 1 bar, 293 K)
Canada	3	5 (15 min)	21	-		0.3 0.052	20 22	offices homes
Germany	5	2 x MAC (5 min) average	8	0.1 (1.2 h) 0.05 (24 h)	9	-	35	
Finland	30	75 (15 min)	1	-		0.08 daily av. 0.16 hourly av.	35	
Italy	-	-		-				
The Netherlands	2	-	40	-		0.16 (1 h) 0.08 (24 h)	43 43	
Norway	-	-		-		-		
Sweedan	2	5, 15 min	4	-		0.2 0.15	12 10	supply air 1/10 of MAC, max. value for 24 h /5/
Switzerland	3	-	6	a) 0.04 (24h) 0.05 b) 0.015 c)	16 37	d)		a) 24 h mean value ought to be exceeded only once a year b) 95% of 1.2 h mean values of a year 0.05 ppm c) annual arithmetic mean d) there are no building regulations for kitchens with gas-powered furnaces
U.K.	3	5 (10 min)	17	-		-		
U.S.A.	3	5 (15 min)	21	-		0.3	20	offices
WHO				0.16	10	0.21 1 hour 0.08 24 hour		AIC: Guideline value, based on effects other than cancer or odour/annoyance

MAC =Maximum Allowable Concentration at the work space 8 h/d
ME-value =Maximum Environmental Value
AIC =Acceptable Indoor Concentration

HOUSE DEPRESSURIZATION TOLERANCE OF MID-EFFICIENCY GAS FURNACES

APPENDIX 1

COMMUNICATIONS WITH MANUFACTURERS

MID-EFFICIENCY FURNACE MANUFACTURES - PHONE # AND ADDRESS

Letters to Manufacturers

1-519-653-6245
Clare Home Comfort Products
223 King Street
Cambridge, Ontario
N3H 4T5

1-416-621-9302
Lennox Industries
400 Norris Glen Road
Etobicoke, Ontario
M9C 1H5

1-519-753-8471
Intercity Products/Keeprite/Heil - Quaker
44 Elgin
Branford, Ontario
N3T 5P4

1-615-793-0450
Heil - Quaker
P.O. 3005
Lavergna, Tennessee
USA
37086

1-416-527-9194
Rheem Air Conditioning Division
128 Barton Street West
Hamilton, Ontario
Z8N 3P3

1-316-832-6300
Evcon Industries Inc./Coleman
3110 North Mead
P.O. 19014
Wichita, Kansas
672049014

1-416-569-9111
Evcon Industries Inc./Coleman
3115 Pepermill Crt
Mississauga, Ontario
L5L 4X5

1-403-436-5920
Climate Master
Division of Bow Valley Resources Ltd
6130-97th Street
Emonton, Alberta
T6E 3J4

1-416-527-9194
Carrier Canada Ltd
8100 Dixie Road
Bramalea, Ontario
L6T 2J8

1-519-682-2062
DMO (Airco/Duo-matic/Olsen) Inc.
P.O. Box 900
Tilbury, Ontario
N0P 2L0

1-416-945-5446
Grimsby Stove and Furnace Ltd.
Grimsby, Ontario
L3M 1X4

1-416-890-7470
York Air Conditioning, Borg Warner
375 Matheson Blvd E,
Mississauga, Ontario
L4Z 1XE

1-416-624-0200
S.A. Armstrong Furnaces Inc.
23 Bertrand Ave,
Scarborough, Ont
M1L 2P3

1-319-622-5511
Amana Refrigeration
Amana, Iowa
USA
52204

1-506-536-6672
Ent Fawcett
Lorne Street
Sackville, NB
E0A 1K0

1-416-845-7558
Intertherm\ GL Products
1030 Eighth Line
Oakville, Ontario
L5J 5C4

1-519-653-7129
Preston Brock Mfg
3035 Industrial Rd,
Cambridge, Ont.,
N3H 4T8

1-412-662-4400
Reznor
Mckinley Av.,
Mercer, Pa
16137

1-501-646-4311
Ruud Air Conditioning
P.O. Box 64444,
Fort Smith, Arizona
USA
72906-0444

1-705-743-4746
Trent Metals
P.O. Box 1088
Peterborough, Ont
K9J 7H4

1-604-359-7296
Valley Comfort Systems Inc
Box 15,
Crescent Valley, B.C.
V0G 1H0

April 24, 1990

Canada
Street
Southern Ontario

Dear Manufacturer,

Re - CMHC research on improving the resistance of induced draft, mid-efficiency appliances to pressure induced spillage in tighter Canadian housing

CMHC is funding research into improving the venting performance of induced draft gas furnaces operating in energy efficient houses. **Sheltair Scientific has been chosen**, (through a competitive process), to assist in this work. We have inclosed with this letter our work plan, so that you can become familiar with the objectives of the project and see the value in participating. We are especially hopeful that you will invite us to your manufacturing plant at the end of July, to discuss issues concerning I.D. furnaces. But first, let me give you some background.

Previous research[1] showed that **some I.D. furnaces were susceptible to spillage** at very low house depressurization (ie. 10 to 20 Pascals). Energy efficient housing programs and inspection authorities have been relying on I.D. furnaces as a way to avoid pressure induced spillage and associated air quality hazards. Research showed that some, not all furnaces on the market, experienced spillage from leaky fan assemblies and other design flaws, manufacturing defects and poor installation practises.

In our opinion the problem is minor, and slight changes could completely eliminate the susceptibility of these appliances to pressure induced spillage. From reading our work plan you can see that we intend to use a combination of field visits and lab tests to establish the severity of the problem and experiment with solutions. We would then

---

[1]. House Depressurization Limits for Mid-Efficiency Gas Fired Furnaces, completed for Energy, Mines, and Resources, Sheltair, March 1989

like to visit a number of major Canadian manufactures to share the information collected, and to discuss the difficulties with making changes to the design of current models.

Our expertise is with building, ventilation, and heating systems at the residential level. We are best known for our field research and our understanding of the interaction of systems in houses. While Sheltair is not a furnace manufacturer, we are very familiar with how equipment is being used and installed in the field, and, with the major changes that are occurring in how Canadian houses are being built and operated. We believe that by working with you, the furnace manufacturing industry, we can quickly move towards more effective venting designs.

We would now like to set up time to hold a 2 1/2 hour seminar at your place of business. We are proposing a morning meeting consisting of a one hour demonstration workshop and one and a half hour lecture and discussion. We will be in your area during the week of July 29 to August 3, 1990. The seminar will be a chance for us to share the information we have collected on spillage hazards and give you a run down on how housing trends and building code changes might affect furnace performance in Canadian houses. As you might guess, we have limited funding, and may not be able to visit every manufacturer. We will be calling you shortly to see whether or not you are interested.

Sincerely,

Peter Moffatt

Note: The seminar is intended as a technical information sharing session. It will be most appropriate for design engineers. Marketing people may be interested in the lecture on housing trends which will follow the workshop on spillage hazards and testing.

SPILLAGE FROM INDUCED-DRAFT

FURNACES IN TIGHTER CANADIAN HOUSING

A Seminar for Manufacturers of Mid-Efficiency Gas Furnaces

Prepared by:

Sheltair Scientific Ltd.
3661 West 4th Avenue
Vancouver, B.C.
V6R 1P2

Funded by:

Canada Mortgage and Housing Corporation
Research Division
684 Montreal Road
Ottawa, Ontario
K1A 0P7

August, 1990

AGENDA

Introduction and Agenda Review

An Overview of What's Been Happening

Introduction to the House As A System

Changes to Codes and Regulations

Past and Future Applications of I.D. Furnaces

Field Test Results

Break

Lab Test Results

Indoor Air Quality Concerns

Possible Furnace Design Improvements

A New Certification Test

A Commissioning Procedure

PRESENTATION OUTLINE

An Overview of What's Been Happening

* R2000 Ventilation research reveals problems (1988)
* EMR funds research into House Depressurization Limits (1988)
* CSA F326 Committee asks CGA for guidance (1989)
* CGA prepares a draft standard (1990)
* NRC hosts a Co-ordinating Committee
* CMHC funds lab tests & surveys

R2000 Research Reveals Problems

* "Vis" house in Vancouver was an R2000 Dermo house

* Used a new French system for ventilation

* Fresh air provided be humidity controlled inlets subjected to constant home depressurization

* Monitoring by Sheltair showed CO2 levels frequently in 1000 to 1400 ppm range

* Highest CO2 levels correlated with furnace on-time

* Close inspection revealed a side vented ID furnace with multiple spillage problems

* Spillage was difficult to detect visually close to turbulence of ID fan

EMR Funds Research In H.D.L's

* R2000 houses are air tight

* To avoid chimney back drafting the program bans use of natural draft appliances

* Most R2000 houses heat with I.D. gas furnaces
* Vis have results raised concern
* Sheltair Contracted to conduct a field survey
* Five makes of I.D. furnaces were tested
* All furnaces experienced unexpected spillage

CSA F326 Committee Asks for Guidance

* CSA Committee developing a major new ventilation standard
* Draft version of CSA F326 placed limits on extent of House Depressurization
* Limit is 5 Pascals (0.02" H2) for natural draft chimneys
* 10 or 20 Pa for I.D. furnaces
* Committee decides to limit all houses wit h gas furnaces to 5 Pa unless appliance is certified for higher levels.
* Committee asks CGA to develop a standard for manufacturers

CGA Draft a Standard

* new standard tilted "Determining Gas Furnace Sensitivity to House Depressurization"
* Furnace manufacturers are encouraged to try a new test procedure
* Feedback is requested
* Proposed test involves applying a protective pressure at the chimney outlet

Changes to codes & Regulations

* National Building Code
* CSA F326 - Ventilation Requirements
* CGA B149/2.3
* CGSB 51.71

National Building Code Changes

* Part 6 of NBC 90 will prohibit misinstallation of return air vents in furnace rooms

* This doesn't solve the problem of furnaces depressurizing their own space however part of 9 of NBC regains a mechanical ventilation system in all houses

* Part 9 NBC 90 repairs "make-up-air" openings to prevent "excession depressurization" in a dwelling when all exhaust fans are operating if dwelling continues, a "spillage susceptible" fuel-fired heating appliance

CGSB 51.71

* A method to Determine Potential for Pressure-Induced Spillage From Space Heating Appliances, Water Heaters and Fireplaces

* Can be used to screen houses for possibility of significant depressurization using default ELA and exhaust flow

* Provides a step-by-step procedure for creating worst use conditions and measuring extent of Home Depressurization

* If test shows that house exceeds to tolerance of appliance, then a make-up-air system can be installed

* Standard is appearing in 4th Draft this fall for ballot

Past and Future applications of I.D. furnaces

* Designed to be an energy efficient replacement furnace
* mandated for use in energy efficient home programs
* With the previously mentioned housing trends and code changes the I.D. furnace will be relied upon as an economical solution to pressure induced spillage
* could eliminate the need for relief air and combustion air

Designed to be an Energy Efficient Replacement Furnace

* Capable of being commonly venting with a naturally aspirated DHW tank

* Relied on for both energy efficient and performance in an air tight house

* When envelope are made more efficient there is no economic justification for a condensing gas furnace

With the previously mentioned housing trends and code changes, I.D. furnaces will be received upon as an economical solution to presume induced spillage.

* Guaranteeing no house Depressurization may be a costly endeavour for code writing bodies.

* May be easier to rely upon appliances that are not effected by typical level of house depressurization

* With slight design changes the I.D. furnace could fit this bill

* Relying on condensing gas furnace for track built housing is out of the question.

* Costs of I.D. Furnaces should come down.

I.D. Furnaces could Eliminate the Need for Relief Air and Combustion Air

* Pressure imbalances between zones in the house are starting to cause problems

* Combustion air is typically acting as a relief opening and gives people a wrong impression of safety

* There are several economic advantages to eliminating belief and combustion air opening that would be an incentive for builders/homeowners

Field Test Results

* A procedure for detecting combustion gas spillage
* Selection of 5 case study houses
* Six key questions
* Identification of spillage sites
* Further testing on Boilers, PHW's and Power Venting Kits (optional)

A procedure for Detecting Combustion Gas

* See Figure "Equipment Set-up"

* Smoke Pencil for detecting direction of air flow

* Co2 Portable Inflated Analyzer Measuring in PPM

* Other equipment such CO, Analyzer, Thermistor, RAB Dedesco

* Door fan to depressurize house

Selection of 5 Case Study Houses

* Tested all E.D. furnaces that are currently available in B.C.
* See table describing houses for details (decided to use names of appliances because they performed identically)
* 2 - R-20000's, 2 conventional new houses, 1 - older house (of the 5 houses --)
* One appliance side vented, 3 - covented with DHW appliance, 1 - individually vertically vented

Six Key Questions

* Refer to copies (distributed) of Sheltair's report
* A summary of Questions and results in brief on hand out
* Stress that those are trends and not individual furnaces
* We looked at appliance as a system and did not try to quantify the leakage in the field

Identification of Spillage Sites

* Axel Hole was the most important leakage site
* Joins in blower housing and basket between housing and furnace with the next most important
* Vent safety spillage switch, leaked depending upon design
* Flue Connector joins (especially if furnace coupling)

House Depressurization

* In 50% of new houses an exhaust of 113 L/S will create >5 Pascals depressurization
* In 20% of new houses 113 L/S will create 10 Pascals of depressurization
* Significant amounts of house depressurization are already occurring on a regular basis in Canadian houses
* Make-up air opening are seldom an effective solution because they used to be so large (see Figure)

Approaching the House As A System

* Homes have become a system
* Furnaces are significantly a part of that system
* Manufacturers must re-define their market to determine what are suitable house "systems"
* No longer possible to turn a "blind-eye" to system problems
* Codes and Standards combine with increasing occupant concerns to re-define market for I.D. furnaces

* Decreasing ELA's are probably inevitable

* Average ELA was 1000 cm2

* Energy Efficient (R200) houses 300 to 500 cm2

Air Change Rates and Air Quality

* Recommended air change rate is 0.3 ACH

* 70% of new houses had average rates of less than 0.3

* Average for new houses is 1/4/hr.

* 30% of new houses have air change rates less than 0.1

* In a smaller home an air change of 0.1 is equivalent to only 11L/S of fresh air supply

* In 50 % of new houses the air change is inadequate to control formaldehyde emissions (see Figure)

* If combustion gas spillage is a regular occurrence then it will also have greater impact in tighter houses

* Controlled ventilation has become a code requirement recommended ventilation through natural in filtration

Ventilation Systems

* CMHC recently awarded a contract to Sheltair to complete a cross-Canada survey of ventilation systems in 200 houses

* Average flows for installed fans were calculated (See Table)

* Combination of a bathroom fan, a kitchen fan and a clothes dryer totals 113 L/S

* Doron draft kitchen fans often blow 150 L/S on their own

CMHC Funds Lab Tests and Surveys

* Sheltair is awarded a contract

* Work plan includes:

  - field test other types of I.D. appliances
  - lab test I.D. furnaces to quantity spillage
  - use computer models to evaluate health and safety concern
  - assist CGA in designing certification test and commissioning procedures

* project completion in September

* Published results available through Tom Hamlin, CMHC, Ottawa

The House as a System

* Air tightness characteristics of Canadian Houses
* Air change rates & air quality
* Ventilation systems
* House depressurization
* Approaching the House as a System

Air Tightness Characteristics of Canadian Houses

* Equivalent Leakage Area (ELA) is size of combined leakage openings in envelope

* For the past 50 years or so houses have become progressively more airtight due to:

  -New materials
  -comfort demands
  -energy conservation

* ELA's have decreased 30% in last 8 years alone (see Figure) based on 250 house Cross-Canada Survey

* positive pressure is assumed to simulate house depressurization

NRC Hosts a Co-ordinating Committee

* "Coordinating Committee on Combustion Venting" (CCCU)
* includes CGA and other concerned groups
* Mandate is to report to National Building Code Associate Committee
* Objectives are:
    * To encourage the incorporation, in standards and in the National Building Code, of requirements that will help to ensure the safe operation of combustion venting systems by providing a forum through which the most current technical knowledge on the subject of combustion venting can be made available to the committees responsible for the relevant standards and parts of the National Building Code.
    * To encourage the greatest possible degree of uniformity and to minimize conflicts in combustion venting requirements in standards and the National Building Code by providing a forum through which each committee can be made aware of what the other committees are planning so that it can adopt parallel measures where that seems appropriate and alert the other committees to possible conflicts where that seems necessary.
* will meet annually (in November)

Field testing of other appliances (optional)

* Gas boilers had similar leakage sites

* The John Wood DHW performed extremes well with a sealed, side vented, plastic flue

* The field power venter performed extremes well because the fan is located outside envelope and depressurize es the entire flue

* The Tjernlund leaked as badly as the worst I.D. furnace

Lab Test Results

* Design of test chamber (Figure)
* Measuring Generation Rates (Graph and Table)
* Major spillage occurring from appliance - not flue connector (appliance vs Flue connector)

Design of Test Chamber

* Airtight room 8' * 8' * 8'

* Ability to control and measure air flow in and out of chamber

* Monitoring temperature Pressure CO2, CO, Humidity with a computer data Acquisition System

* Two Furnaces 1 - 45,000 BTU 1 - 66,000 BTU (input)

Measuring Generation Rates

* Graph shows exponential risk in CO2 generation rate at Higher Pressure

* Table show results from all tests

* The two furnaces performed in a similar fashion

. . Major Spillage Occupying From Appliance not Flue Connector

* Unsealed and sealed tests showed almost identical results for both appliances

* Slightly larger spillage generated from the larger appliance

Indoor Air Quality Concerns

* Natural gas produces a number of pollutants when burned (Tables)
* Health and welfare limits
* NO2 has been shown to increase respitory problems in children (NO2 is a special concern)
* Impact of measured generation rates on Air Quality (Tables 1-4) (Predicting pollution levels based on lab test results)
* How much spillage is too much?

Natural Gas Produces a Number of Pollutants

* Refer to table on gas emissions

* NO2 is the pollutant of most concern

* Interesting to note that aldehydes are also produced

Table Effects of Exposure to Nitrogen Dioxide in the Home on the Incidence of Acute Respiratory Disease in Epidemiology Studies Involving Gas Stoves[a]

Pollutant	NO_2 Concentration $\mu g/m^3$ (ppm)	Study Population	Effects	Reference
		Studies of Children		
NO_2 plus other gas stove combustion products	NO_2 concentration not measured at time of study	2554 children from homes using gas to cook compared to 3204 children from homes using electricity. Ages 6-11	Bronchitis, day or night cough, morning cough, cold going to chest, wheeze, and asthma increased in children in homes with gas stoves.	Melia et al. (1977)
NO_2 plus other gas stove combustion products	NO_2 concentration not measured in same homes studied	4827 children ages 5-10	Higher incidence of respiratory symptoms and disease associated with gas stoves.	Melia et al. (1979)
NO_2 plus other gas stove combustion products	Kitchens: 9-596 (gas) (0.005-0.317) 11-353 (electric) (0.006-0.188) Bedrooms: 7.5-318 (gas) (0.004-0.169) 6-70 (electric) (0.003-0.037) (by triethanolamine diffusion samplers)	808 6- and 7-year olds	Higher incidence of respiratory illness in gas-stove homes. No apparent statistical relationship between lung function tests and exposure.	Florey et al. (1979) Companion paper to Melia et al. (1979); Goldstein et al. (1979)
NO_2 plus other gas stove combustion products	Sample of households 24-hr average: gas (0.005-0.11): electric (0-0.06): outdoors (0.015-0.05); monitoring location not reported; 24-hr averages by modified Jacobs-Hochheiser (sodium arsenite); peaks by chemiluminescence	128 children 0-5 346 children 6-10 421 children 11-15	No significant difference in reported respiratory illness between homes with gas and electric stoves in children from birth to 12 years. No differences in lung function tests.	Mitchell et al. (1974); See also Keller et al. (1979a, b)
NO_2 plus other gas stove combustion products	Sample of same households as reported above but no new monitoring reporting	174 children under 12	No evidence that cooking mode is associated with the incidence of acute respiratory illness.	Keller et al. (1979b)
NO_2 plus other gas stove combustion products	95 percentile of 24-hr indoor average: 39-116 $\mu g/m^3$ (0.02-0.06) (gas); 17.6-95.2 $\mu g/m^3$ (0.01-0.05) (electric); frequent peaks (gas) > 1100 $\mu g/m^3$ (0.6 ppm); 24-hr by modified sodium arsenite; peaks by chemiluminescence	8120 children 6-10; 6 different communities; data collected also on history of illness before the age of 2.	Significant association between history of serious respiratory illness before age 2 and use of gas stoves. Small but statistically significant decrements in lung function tests ($FEV_{1.0}$[b] = 16 ml, FVC[c] = 18 ml) for those from gas stove homes compared with children from homes with electric stoves.	Speizer et al. (1980)

NO_2 Has Been Shown to Increase Respiratory Infections

* See handout
* Studies have shown that children are the most susceptible
* Adults do not seem to be effected
* NO_2 can be sensed at 12 ppm in the houses that caused problems NO_2 was in the range of (.005 ppm to .11 ppm)

(.005 - .11ppm) american houses with gas stoves

[ratio is approximately .0000359 ppm NO_2/1 ppm CO_2]

Impact of Measured Generation Rates on Air Quality

* (Table 1) Even with high air change rates a small room can reach 2800 ppm CO_2
* (Table 2) The concentration will still boost CO_2 Levels in a large house without the contribution from occupants
* (Table 3) Long furnace run times will cause quick build-up of CO_2 concentrations
* (Table 4) The effect of higher depressurization rates is an exponential risk in CO_2 concentrations

How Much Spillage Is Too Much

* Where do we draw the line
* Is any spillage dependable?
* What would the response be from the consumer?

(Open to Discussion)