Combustion Vent Clearances

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ABSTRACT

This study explores two cases of combustion flue clearances. In the first case, temperatures in an attic chimney clearance space were investigated. Seven different tests were conducted that showed temperature effects on the wood joists in the clearance space. The second case explored various insulation and infiltration levels in exterior B vent chases.

A small field study was included to determine the air infiltration rate in existing chases. The average ELA of the three chases tested was about 341 cm^2.

The FLUESIM v5.0 simulation program was used to model various flue configurations using field measured air infiltration data. The computer simulations showed that the worst case temperature rise in an insulated, tightly constructed B-vent flue enclosure is about 9C when the outside air is around 0C.

KEY WORDS

Exterior Chase
Type B Vent
Attic Clearance Space
Solid Fuel Burning Chimneys
Flue Insulation

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- Don Fugler of the Canada Mortgage and Housing Corporation supervised the work and provided valuable insights to all areas of the project.

- Colin Gage, from Victoria Park Community Living, Alena Miller of Hamilton and Marcel Poliquin of Ottawa permitted the air tightness testing on homes that they owned.

The project team consisted of:

- Derek Van Dalen, Ken Ruest, Jeffrey T. Blake, and Anil Parekh of Scanada Consultants Limited,
- Stanley J. Pople and Robert Sculthorp of Underwriters' Laboratories of Canada.

EXECUTIVE SUMMARY

Most fuel-burning equipment standards specify minimum clearances around combustion appliance flues to ensure that surrounding materials are at a safe temperature. Energy conservation concerns and new building codes are affecting these clearances and the air tightness of flue penetrations. This raises concerns about the temperature of nearby combustible materials.

This study is part of CMHC's ongoing research in combustion clearances to aid in code evaluation, and to promote energy efficiency in residential dwelling. The research was performed by Scanada Consultants Limited and Underwriters' Laboratories of Canada.

This study represents exploratory work in the field of combustion clearances. Two investigations were completed:

1) Investigation of attic chimney clearances. A study of the effect of sealing the flue penetration into the attic, and varying the clearances, on the temperature of combustible materials present in the joist box.

2) Exterior B Vent Chase Temperatures. A study of exterior chase temperatures that result from various levels of insulation, furnace cycling times, and air infiltration rates. A flue simulation program (FLUESIM) was used for this work.

The investigation of attic chimney clearances showed that the temperatures in the joist box increase as the clearance space is reduced and the top and bottom plates are sealed. Surprisingly, insulation in the clearance space increases the temperature of the outer surface of the chimney and the surface temperature of the joists surrounding the chimney are not significantly reduced. In four of the seven tests conducted, the temperatures of the combustibles in the joist space exceeded the maximum temperature rise of 65°C permitted in the CAN/ULC S629 Standard.

Field testing of exterior B vent chases was carried out to determine typical air infiltration rates. The average ELA of the three chases tested was 341 cm^2.

Computer simulation of the exterior B vent chases was attempted in an effort to determine the temperature effects of changing the furnace cycling times, the amount of insulation in the walls of the chase, and the air infiltration rate. The simulation results showed that the worst case temperature rise in an insulated, tightly constructed B vent flue enclosure is approximately 9C.

Étude de la SCHL sur le dégagement des conduits d'évacuation des gaz de combustion

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RÉSUMÉ

La majorité des normes visant les appareils à combustion précisent le dégagement minimal à respecter autour des conduits d'évacuation de façon à garantir une température sûre pour les matériaux environnants. Le souci d'économiser l'énergie et les nouveaux codes du bâtiment exercent des répercussions sur le dégagement à ménager et sur l'étanchéité à l'air du point de pénétration de ces conduits, ce qui n'est pas sans soulever des préoccupations quant à la température des matériaux combustibles à proximité.

L'étude s'inscrit dans le cadre de la recherche permanente que la SCHL consacre au dégagement des conduits d'évacuation en vue de favoriser l'évaluation des codes et l'efficacité énergétique des logements. La recherche a été effectuée par Scanada Consultants Limited et par les Laboratoires des assureurs du Canada (ULC).

Il s'agit de travaux exploratoires concernant le dégagement des conduits d'évacuation des gaz de combustion. Deux études ont été réalisées en ce sens :

1) Étude sur le dégagement des cheminées traversant le vide sous toit. Une étude des effets obtenus sur la température des matériaux combustibles de la niche intérieure en scellant le point de pénétration du conduit d'évacuation au vide sous toit et en faisant varier le dégagement.

2) Étude sur la température de la niche extérieure d'un conduit d'évacuation de type B. L'étude portant sur la température de la niche extérieure résultant des divers niveau d'isolation, de la durée du cycle du générateur, et des taux d'infiltration d'air. Le programme informatique FLUESIM a été utilisé pour ces travaux.

L'étude du dégagement de la cheminée traversant le vide sous toit montre que la température de la niche intérieure augmente selon que le dégagement est réduit et que la lisse et la sablière sont scellés. Fait surprenant, la présence d'isolant dans le dégagement proprement dit fait augmenter la température de la surface extérieure de la cheminée, sans contribuer à réduire de façon appréciable la température superficielle des solives entourant la cheminée. Lors de quatre des sept essais effectués, la température des matériaux combustibles de la niche intérieure dépassait l'augmentation de température maximale de 65°C que prévoit la norme CAN/ULC S629.

L'essai en service des niches extérieures de conduits d'évacuation de type B a été effectué de façon à déterminer les taux typiques d'infiltration d'air. La SFÉ moyenne des trois niches extérieures mises à l'essai était de 341 cm^2.

La simulation informatique des niches extérieures de conduits d'évacuation de type B tentait de déterminer les effets obtenus sur la température en modifiant la durée du cycle du générateur, la quantité d'isolant dans les murs de la niche extérieure, et le taux d'infiltration d'air. Les résultats de la

simulation indiquent que la pire augmentation de température dans une niche extérieure isolée de conduit d'évacuation de type B correspond à 9°C.

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1. INTRODUCTION

Energy conservation in residential dwellings has been widely encouraged by governments and will soon be mandated by building codes. Initially this was due to fuel shortages and increased heating costs, but more recently the desire to reduce pollution and conserve resources has become a significant motivation.

Sealing attic penetrations due to chimneys, flues and vents is one method of reducing the overall building air leakage area and energy consumption. However, this energy conservation practice raises concerns about the temperature of nearby combustible materials.

Scanada Consultants Limited and Underwriters' Laboratories of Canada have investigated two different aspects of vent clearances. This report details the research and presents the findings. This exploratory work was commissioned by the Research Division of the Canada Mortgage and Housing Corporation.

1.1 Background

Residential dwellings are required to use type A or B combustion gas vents or flues depending on the combustion gases to be vented. Type A flues are used for venting the combustion gases from wood burning appliances while Type B vents are used for venting the combustion gases from gas burning appliances. Type A and B vents can be mounted internally, extending through the interior house envelope, or can be mounted on the exterior of the building envelope.

Interior chimneys and vents often extend through the housing envelope at the attic level. The clearance space between the chimney and the structural members is specified in the National Building Code (NBC section 9.25.5.7), which also requires the clearance to be sealed with a non-combustible material.

External gas vents are enclosed to avoid condensation of flue gases, reduce possible backdrafting, provide protection from physical damage, and to provide a wind break. The current Standard for gas vent testing CAN/ULC-S605-M91 requires that an exterior vent be enclosed with a single layer of 9.5 mm plywood. The Natural Gas Installation code CAN/CGA-B149.1, under Clause 7.17.1, requires that the external vent be *adequately* insulated.

At the November 1990 meeting of the CGA B149 Venting and Ventilation subcommittee, the question of enclosing and insulating exterior mounted Type 'B' gas vents was discussed, but not resolved. The subcommittee was of the belief that input from inspection authorities should be requested and considered before definitive requirements were developed. To this end a Bulletin was submitted to the IGAC for consideration and comment.

The results of the bulletin, which requested a recommendation of insulation levels, were inconclusive. Some provinces felt that the present enclosure requirements were sufficient. Other provinces suggested RSI 3.5 insulation levels.

As there is no data to support an argument that exterior B vent chases should be insulated, the debate over the merits of insulation continues. Also, insulation alone may be ineffective due to high air infiltration rates; the overall heat loss of the enclosure must be considered when evaluating the requirements for enclosure insulation.

1.2 Objectives

The objectives of this study were to examine the requirements for exterior enclosed Type B vents and interior chimney clearances.

> **Objective 1: Interior Chimney Clearances.** Study the temperature effects on the surrounding combustible enclosures when a chimney penetrates the attic from the interior of the house.
>
> **Objective 2: Exterior B Vents Chases.** Study the temperature effects on the surrounding combustible enclosure, where a Type B vent is exterior to the building and enclosed with combustible material (i.e. plywood and insulation). This study would attempt to provide the minimum clearance needed for different amounts of insulation and different ventilation rates in the enclosure. Also this study would provide actual ventilation rates in installed Type B vent enclosures.

The work performed in this project could lead to the development of standards consistent with code requirements.

1.3 Approach

Underwriters' Laboratories of Canada (ULC) and Scanada Consultants Limited have combined their expertise in this area to complete the investigations. Both members have relevant experience and knowledge of flue vent issues.

ULC conducted tests in their laboratories to determine the temperature effects of a chimney on the surrounding structural members. A simple test structure was built, and thermocouples were placed in the cavity surrounding the chimney so that the maximum wood temperatures could be recorded.

Scanada Consultants developed the procedures to perform field testing of the ventilation rates of exterior B vent chases. Originally eight different Type B vent chases representing a variety of home builders and ages were to be tested for air tightness. However, due to budget and time constraints, and the sparse selection of testable chases, only three different chases were tested, two of which contained Type A vents.

A base case was developed with a computer simulation program (CMHC FLUESIM v5.0) to model the temperature effects of different levels of enclosure insulation on a typical installation. Computer simulations were carried out using the infiltration rates obtained from the field investigations, various furnace cycling times and enclosure volumes.

2. TEST PROCEDURES

2.1 Interior Chimney Clearances

A test rig was set up as shown in Figure 1. The construction of the test structure was in basic conformance with the requirements of CAN/ULC-S629-M87 Standard for 650°C Factory-Built Chimneys for a single storey and attic installation. A Type A chimney was purchased and installed on the test rig. The chimney consisted of six, 175 mm ID, one metre sections of ULC listed 650°C chimney. Between the floors of the test rig an enclosure was built surrounding the chimney of 9.5 mm plywood. The edges and corners of the enclosure between the floors were sealed with tape in accordance with the standard. The attic joist clearance space was initially set to 50 mm.

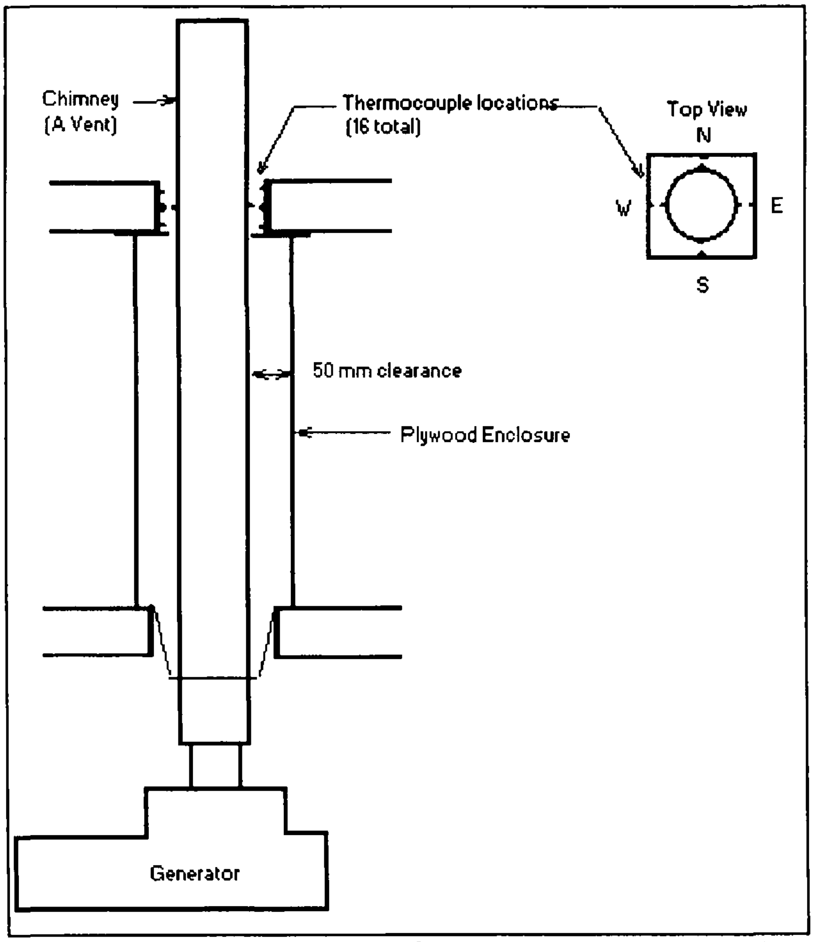


Figure 1: Interior Chimney Clearances Test Installation

The firestops used during these tests incorporated a 302 mm diameter hole for a chimney outside diameter of 298 mm. The manufacturer's ceiling support system was used . The average annular clearance between the hole in the support and chimney outside diameter was 1.5 to 2 mm.

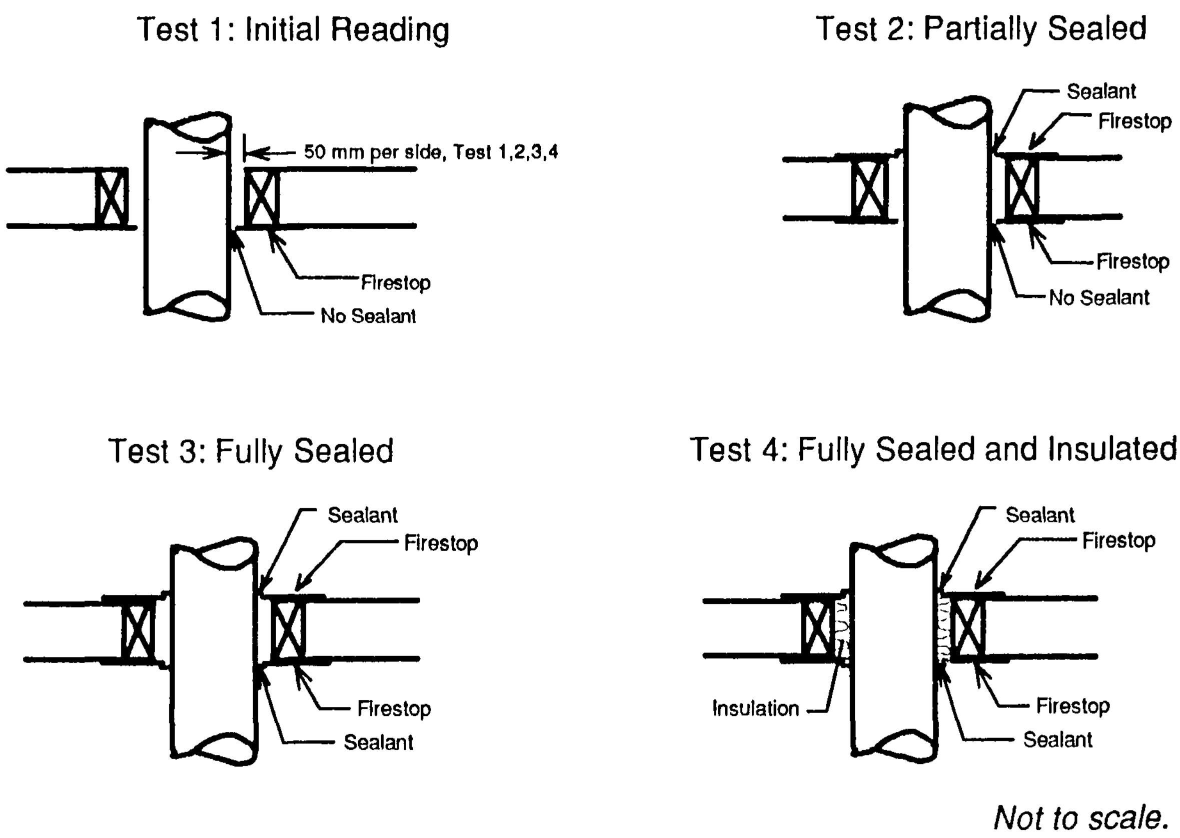
A series of seven tests were performed with varying configurations of the attic penetration (Table 1). Figure 2 shows these different configurations.

Table 1: Summary of Interior Chimney Clearance Tests

Test	Description
1: Initial Case	A firestop was placed on the underside of the clearance space and not sealed.
2: Partially Sealed	A second firestop was installed on the top side of the clearance space and sealed to the chimney.
3: Fully Sealed	The two firestops were sealed to the chimney.
4: Fully Sealed and Insulated	Insulation was placed in the joist spaces. Both the top and bottom firestops were sealed.
5: 100 mm Clearance Space	The clearance space was increased to 100 mm. The top and the bottom firestops were sealed to the chimney.
6: 150 mm Clearance Space	The clearance space was increased to 150 mm. The top and the bottom firestops were sealed to the chimney.
7: 0 mm Clearance Space	The clearance space was reduced to 0 mm. The top and the bottom firestops were sealed to the chimney.

Wood temperatures in the joist space were measured by thermocouples located as indicated in Figure 1. Three thermocouples were installed on each of the four sides of the joist space at the location of the smallest clearance. The three thermocouples were located in the lower, mid and upper sections of the joist space. Four other thermocouples were placed on the outside of the chimney surface. The surface temperatures of the chimney were recorded for reference purposes.

A gas generator was attached to the base of the chimney and fired to produce flue gas temperatures of 645°C for each test. Each test was continued until stabilized conditions were achieved (i.e. a minimal change <1°C in successive 15 minute readings).



Note: Tests 5, 6, and 7 will be similar to Test 3, but with the clearances indicated below per side for each test.

i.e.	Test 5:	50 mm + 50 mm = 100 mm
	Test 6:	50 mm + 100 mm = 150 mm
	Test 7:	50 mm - 50 mm = 0 mm

Figure 2: Interior Chimney Clearance Details

Appendix A contains photographs of the test rig and the different configurations of the joist space.

2.2 Exterior B Vent Chases

2.2.1 Field Testing of Exterior B Vent Chases

Existing exterior B vent chases were located and tested for air tightness.

Locating the Chases

This task commenced with a drive-through survey of existing housing developments in Peel, Halton, Hamilton-Wentworth, and the Ottawa regions. Houses and row houses built with an exterior chase encasing a Type A or B vent pipe were targeted. Finding houses containing the appropriate chases was difficult as most houses that have gas appliances contain a flue that runs vertically through the inside building envelope. The latest residential developments eliminate the need for a chase, as gas fireplaces and high efficiency condensing gas furnaces vent horizontally. In new construction, only Type A vent pipes are enclosed in an exterior chase. In looking for chases to test, we attempted to find a range of house ages and home builders.

A list containing all social housing projects in Toronto, Hamilton and points in between was obtained from CMHC. It was anticipated that this might help in the search for exterior chases.

Several developments in Mississauga, (Erin Mills, Meadowvale), Burlington and Hamilton had houses where an exterior chase was constructed to contain a vent. It was preferred to have access to the interior of the chase from the underside to avoid damaging the exterior facade of the chase while carrying out the test. In some instances, chases were considered where access to the interior of the chase was only possible through the side of the chase, and the exterior of the chase was covered with vinyl siding.

The homeowners were approached, during evenings and on weekends, to explain the project and seek their permission to perform an air tightness test on their chase. Most of the homeowners did not want to participate in the study, even when a small amount of money (typically $ 80.00) was offered to them for the use of their chase. Homeowners offered the following reasons for not allowing the testing on their chases:

- The exterior of their house would be damaged. They did not feel confident that the exterior could be repaired to the original condition.
- The testing could damage the existing vent. They did not want the risk or bother of fixing a damaged vent.

- The hole in the chase was viewed as a potential for unwanted problems such as animals entering and water damage.

The following four homeowners granted permission for testing.

- Erin Mills. A house with a chase surrounding a Type A vent pipe. Permission was granted after discussion with the homeowner. However, further investigation of the chase revealed that it would be too difficult to test as a hole was required to be cut approximately nine feet above ground level on the exterior of the chase.
- Burlington. A townhouse development was found that has exterior enclosures for B vents from the furnace. Permission to access the interior of one of the chases from the bottom of the chase was granted. The townhouses are approximately three months old.
- Hamilton. A house with an exterior chase containing an A vent was found. Permission to test the chase was granted. A clearance space existed between the ground and the underside of the chase. After talking with the homeowner, it was discovered that the chase was accessible through a hatch in the attic. The house is approximately one year old.
- Orleans. Several homes in the Ottawa area were found that had exterior chases constructed. Permission was granted from one of the homeowners to conduct an air tightness test. Access to the chase was from the bottom.

All of the above chases were selected because they could be easily tested and restored to their original exterior condition. All have vinyl siding which can be pried off, and some can be tested by accessing the underside of the chase.

Two other locations in Burlington and Mississauga also have exterior chases, however aluminum siding was used on the exterior of the chase and it was not possible to access the underside of the chase. In Hamilton several locations had Type B vent pipe encased in a masonry chimney. (This did not seem to be a retrofit measure as the homes were less than 5 years old.) Both masonry and aluminum siding would present a host of problems in trying to access the interior of an exterior chase.

Exterior chases have been found in Oakville, however they enclosed type A vent pipes and the lower section of the chimney was of masonry construction.

New houses in Erin Mills/Meadowvale have an exterior chase for a Type A vent pipe from a ground floor fireplace. However the exterior of the houses are finished with painted wood siding. Homeowners have insisted that if their chase was to be tested, the wood siding must be replaced with identical stock. The builder was contacted, but identical stock was not available.

Testing the Chases

The first air tightness test was conducted in Burlington. The interior of the chase was accessed by removing the exterior aluminum bottom plate and cutting an 180 mm diameter hole in the bottom of the wooden chase. The CMHC Duct Test Rig (DTR) was attached to the hole, through the use of galvanized steel elbows. The DTR was started with the orifice on the B setting. Pressure readings and flow readings were read from the DTR and compared with a reading from a separate micromanometer. The orifice setting was changed to a narrower opening, the C setting, resulting in an increased flow. The orifice was enlarged, to the A setting, and the flow decreased. The results indicated that the chase was not being depressurized and the DTR was causing a pressure difference between the elbow and the outside air only.

The test was repeated on the same chase, but the hole in the bottom of the chase was increased until it was 300 mm by 300 mm square, the largest hole possible in the underside of the chase. The intention was to make a hole the size of the opening of the DTR, to reduce the amount of flow restriction between the chase and the DTR. The DTR was connected to the chase using polyethylene plastic sheeting and duct tape.

The second test was performed on a house in Hamilton. The chase was accessed through a hatch in the attic. The DTR was attached directly to the chase, polyethylene plastic sheeting and duct tape was used to seal the sides of the DTR to the side of the hatch.

The third test was performed on a house in Orleans, Ontario. The chase was accessed by removing the bottom plate of the chase. The DTR was attached to the chase by using polyethylene plastic sheeting and duct tape.

Appendix B contains photographs of the different field test sites.

The field data was used to calculate an effective leakage area of the chase, using the procedures as described in Section 7.1 through 7.7 of the Canada General Standards Board publication CAN/CGSB-149.10-M86.

Testing on eight different chases was desired, and much time and effort was devoted to finding and obtaining permission to test this number of chases. Project limitations caused that number to be reduced to three chases.

2.2.2 Computer Simulation

The computer simulation portion of this project involved using an existing flue simulation program to model the affect of flue enclosure variations on enclosure temperatures. CMHC's FLUESIM v5.0 and The Gas Research Institute's VENT-II were obtained for this work. These programs are designed to simulate combustion vent systems and predict temperatures, flows, pressures, and the formation of condensation in the vent system. Both programs were evaluated to determine their usefulness in this study.

The evaluation focused on the ability of the software to simulate exterior chases. Both programs allowed for the use of Type B vents in exterior chases and the ability to vary some environmental conditions at the appliance. VENT-II allowed the entry of the depressurization at the appliance and changing the heat transfer coefficient multiplier. FLUESIM allowed the entry of a specific structure equivalent leakage area. It was recognized that neither one of the programs could completely simulate the operation of an exterior B vent chase. FLUESIM was selected because of the flexibility and ease of changing the equivalent leakage area.

The procedure that was ultimately used to estimate the effect of various air leakage rates and insulation levels on flue enclosure temperature was based on a combination of FLUESIM and simple engineering calculations. However, several other approaches were attempted before arriving at a suitable approach.

Approach 1: FLUESIM House ELA

Five different simulation models were created in FLUESIM to simulate the effect of different levels of insulation, the effect of furnace cycling, and the air tightness of the exterior chase. The program did not allow the modelling of just exterior chases. The exterior chase was to assumed to be the complete structure containing the gas appliance. This would allow the ELA of the structure to be considered as the ELA of the exterior chase.

Two of the five models were created to help refine the model and better simulate an exterior chase. Results from these two models were compared with laboratory test data of an exterior chase[1].

Of the remaining three models, one was the base case, which did not contain any insulation. The second model had a chase that contained RSI 1.8 insulation in each of the enclosing walls. The third model contained RSI 3.5 insulation in the walls of the chase. No other models were created as RSI 3.5 is the maximum allowed input for enclosure insulation in FLUESIM.

The furnace cycling was modelled by varying the run times for each model. The run times were set to 300 seconds, 600 seconds and 900 seconds for an air tight scenario and again for a leaky case. The furnace was turned off 60 seconds before the simulation ended. These times were selected as typical furnace operating times.
A typical FLUESIM model contains the furnace inside the structure. The chase can be placed inside or outside of the structure. The models that were created for this study, contained a chase inside of the house. As the air leakage into the chase cannot be directly adjusted, it was indirectly adjusted by changing the building envelope equivalent leakage area (ELA). For the tight case, the building envelope ELA was set to the smallest possible area that would allow complete combustion (0.011 m^2) and the flow exponent was set to 0.651. For the leaky scenario, the building envelope ELA was set to 0.0220 m^2 and the flow exponent was set to 0.0651 which are typical values of the calculated ELA from the field testing results. Although changing the ELA in this way would not directly affect the interior chase, it was one way to study the effects of varying the ELA on the flue temperatures, short of modifying FLUESIM.

Program inputs cannot be printed directly from FLUESIM. Some inputs are contained in printouts of the output files. Appendix E contains a summary of the output files from FLUESIM.

The results from the different runs were analyzed and it was found that changing the ELA from a small value (0.011 m^2) to a typical chase leakage area (0.0220 m^2), reduced the combustion temperature of the gas appliance. Consequently the flue gas temperature and the temperature of the flue pipe were reduced. This was an unreasonable result, and another approach was tried.

Approach 2: FLUESIM Code Modifications

[1] Laboratory test data obtained from Underwriters' Laboratories of Canada and James A. Ryder Mfg. Inc.

The FLUESIM source code was examined to determine how the chase air tightness is modeled. An attempt was made to make minor modifications to FLUESIM that would enable the modelling of the air infiltration of exterior chases. Equivalent leakage area equations were found that seemed to represent how the chase tightness was determined. Further investigation however, indicated that these ELAs were used to determine the flow of the combustion products in the chimney and do not effect the chase leakage rate.

It was concluded that the code modifications required to implement the required changes would be too extensive and well beyond the scope of this project.

Approach 3: FLUESIM Heat Loss Factors & Air Leakage Rate Estimates

The FLUESIM chase inputs were examined to determine if it was possible to indirectly incorporate an air infiltration rate in the properties of the chase. The input screen for the "Chase Characteristics" contains three "Heat Loss Factors" that represent the heat transfer, in W/m^2C, through the flue pipe (conduction), across the enclosure air space (convection and radiation), and through the enclosure material (conduction). The heat loss factor for the enclosure material can be modified in the range of from 0.01 W/m^2C to 200 W/m^2C.

This factor is used to represent an "effective" heat loss factor that includes the heat loss due to conduction through the enclosure material and infiltration of outside air through the chase enclosure. The infiltration heat loss is calculated using the LBL infiltration model and the average field-determined chase ELA.

3. TEST RESULTS

3.1 Interior Chimney Clearances

Table 2 shows the temperature rise summary of the Interior Chimney Clearances study. The thermocouple location and number are shown in the left-most column in the table. The thermocouples register the temperature difference (i.e., the temperature rise above the ambient temperature). The ambient temperature for each test is shown on the second row of the table. Complete and detailed temperature readings are presented in Appendix C.

The first test (Initial Readings) produced the lowest average temperatures. The temperature variation evident in this test may be attributed to the absence of a top firestop and the resulting air movement.

The highest average temperatures in the joist box, with standard 50 mm clearance, occurred during the second test (Partially Sealed) where the top firestop was sealed and the bottom firestop was unsealed. The higher temperatures may be due to the warmer air from the enclosed section between floors rising into the joist box. It would seem that it is preferable to have the bottom firestops sealed, rather than the top, in order to keep the temperature rise on combustibles in the ceiling joist box to a minimum. Of course, this is the usual case for flue installation.

Temperatures in the fourth test (Fully Sealed and Insulated) which had the insulation in the joist box, were close to temperatures in the second test but on average, slightly lower. The highest individual temperature in the joist box, with standard 50 mm clearance, was recorded during this test. Individual temperature readings in the fourth test showed an increased range, most likely due to a variation of the insulation density/application. The surface temperature of the chimney was considerably higher during this test than compared to all other tests (193°C as compared to approximately 130°C).

Table 2: Temperature Rise Summary

T.C. Location (T.C. #)		1: Initial Reading	2: Partially Sealed	3: Fully Sealed	4: Fully Sealed and Insulated	5: 100 mm Clearance	6: 150 mm Clearance	7: 0 mm Clearance
Ambient - °C (60)		22.1	22.9	24.0	23.3	23.7	23.9	21.7
Joist Box - ΔT°C								
Top	North (74)	9.9	82.2	69.9	55.6	50.6	39.3	111.2
	East (71)	24.5	80.8	65.3	60.2	57.5	39.4	103.7
	South (61)	11.3	84.9	68.2	52.5	48.4	40.3	105.3
	West (64)	7.4	76.9	66.9	42.7	45.8	37.3	111.4
	Avg.	13.3	81.2	67.6	52.8	50.6	39.1	107.9
Mid	North (75)	14.8	78.9	68.4	84.6	53.1	38.7	132.0
	East (72)	29.8	73.8	67.9	69.6	54.8	43.3	130.8
	South (62)	17.0	78.0	68.1	76.8	54.5	41.1	114.7
	West (65)	13.5	76.1	68.6	73.0	51.9	41.3	122.0
	Avg.	18.8	76.7	68.3	76.0	53.6	41.1	124.9
Bottom	North (76)	22.4	70.8	64.4	68.5	48.3	36.1	130.9
	East (73)	33.4	71.6	71.2	65.5	51.6	42.1	112.4
	South (63)	28.4	73.0	64.1	93.7	50.6	38.9	120.9
	West (66)	21.1	70.2	64.3	72.9	46.1	38.2	123.6
	Avg.	26.3	71.4	66.0	75.2	49.2	38.8	122.0
Chimney OD - ΔT°C								
Mid	North (70)	68.7	128.1	129.5	197.4	122.2	111.3	133.1
	East (69)	73.7	123.9	128.6	189.4	123.5	113.3	140.2
	South (68)	65.5	138.0	129.0	194.2	119.5	110.4	111.1
	West (67)	61.9	135.4	127.6	192.3	118.5	106.2	137.0
	Avg.	67.5	131.4	128.7	193.3	120.9	110.3	130.4

The third, fifth, sixth and seventh tests were similar except for the clearances. The effect of these clearances when compared to the manufacturer's specified clearance of 50 mm in the third test are shown in Table 3.

Table 3: Comparison of Clearance Variation and Average Temperature Change

Test Comparison	Clearance Variation	Change in Average Surface Temperature of Combustibles in Joist Box (Approximately)
3 to 5	50 mm to 100 mm	-16°C
3 to 6	50 mm to 150 mm	-28°C
3 to 7	50 mm to 0 mm	+51°C

3.2 Exterior B Vent Chases

3.2.1 Field Testing of Exterior Chases

Permission was obtained from four homeowners, representing a variety of different house ages and home builders, to perform air tightness tests. Three different chases were tested. The fourth chase was judged to be too difficult to test.

Test 1: Townhouse
Location: Burlington
Year of Construction: 1993

The chase was used for a Type B vent which exhausted combustion gases from the gas water heater and the gas furnace. The chase was accessed through a hole cut in the bottom of the enclosure. The DTR (Duct Test Rig) was attached to the opening with duct tape and plastic. Readings were taken with the DTR orifice set to the B setting and the C setting. Pressure readings in the chase were recorded using a separate electronic micromanometer.

In this test three pressure readings were obtained for each orifice setting. The Flow readings, in units of pressure (Pa), were converted to litres/second using the procedure provided in the DTR manual. ELA calculations were performed for the combined set of readings. Table 4 shows the ELA results for this test.

Table 4: Equivalent Leakage Area Calculation Results for Test 1

	Equivalent Leakage Area (m^2)	Flow Exponent
B&C Orifice Setting	0.0583	0.8787

Test 2: Single Family House
Location: Hamilton
Year of Construction: 1992

The chase was used for a Type A vent pipe. The chase was accessed through a hatch in the attic. The CMHC Duct Test Rig (DTR) was attached to the hatch opening and sealed with duct tape and plastic. Readings were taken with the DTR orifice set to the B and C settings. Pressure readings in the chase were recorded using a separate electronic micromanometer.

The equivalent leakage area was calculated using the results of this test. Table 5 summarizes the results obtained.

Table 5: Equivalent Leakage Area Calculation Results for Test 2

	Equivalent Leakage Area (m^2)	Flow Exponent
B&C Orifice Setting	0.0220	0.6509

Test 3: Single Family House
Location: Ottawa
Year of Construction: 1983

The chase was used to enclose a Type A vent from a fireplace. The chase was insulated with fibreglass batts on three sides and opened to the manufactured fireplace box enclosure for the full height of the main floor. At the second storey header the chase was closed around the A-vent and insulated. The clearance around the A vent was large and it was assumed that the full chase was depressurized during the test.

The chase was accessed by removing the bottom piece of plywood from the cantilevered chimney enclosure. The DTR was attached to the opening with duct tape and plastic. Two sets of reading were obtained, both containing flow readings with the DTR orifice set to the B and C settings. Pressure readings in the chase were recorded using a separate electronic micromanometer.

Three ELA calculations were performed. The first calculation used the results of the first set of readings and the flow was adjusted for the outdoor air temperature. The flow was calculated using the procedure provided in the DTR manual. The second calculation used the results from a second set of readings and the flow was calculated using the DTR's Sharp pocket computer. The flows were adjusted for the temperature of the air being extracted from the chase and the actual barometric pressure at the time of the test. The third calculation used the results from a third set of readings. The fan flow was calculated using the DTR's Sharp pocket computer and adjusted for the temperature of the air being extracted from the chase and the barometric pressure at the time of the test. Table 6 summarizes the results obtained.

Table 6: Equivalent Leakage Area Calculation Results for Test 3

	Equivalent Leakage Area (m^2)	Flow Exponent
Calculation 1	0.0209	0.7141
Calculation 2	0.0220	0.6747
Calculation 3	0.0231	0.6314
AVERAGE	0.0220	0.6734

The field testing results and the Equivalent Leakage Area (ELA) calculations are presented in Appendix D. Photographs of the field test sites are contained in Appendix B.

Normalizing the equivalent leakage areas provides a means of comparing air tightness results of the chase testing to air tightness testing of other structures. Table 7 shows the normalized leakage area of the chases tested.

Table 7: Normalized Leakage Values of Chases

Chase Location	ELA	Surface Area (m^2)	NLA (cm^2/m^2)
Test 1: Burlington	0.0583	16.90	34.49
Test 2: Hamilton	0.0220	17.55	12.53
Test 3: Ottawa	0.0220	17.78	12.37
AVERAGE	0.0341	-	19.80

The objective of the field testing was to determine a typical air infiltration rate of an exterior chase. A larger sample is required to arrive at equivalent leakage areas that are representative of the infiltration rate of all existing chases. Procedures should be developed that are not as damaging to the chases as those described above. The new methods should help to convince reluctant homeowners to have their chases tested. This was unfortunately beyond the budget of this study.

3.2.2 Calculation of Chase Temperature Regime

Full simulations were performed using FLUESIM v5.0. Insulation levels in the chase, furnace cycling and equivalent leakage areas were changed. The following describes the results of these runs.

Comparison with Laboratory Test Data

Computer models were generated using FLUESIM v5.0. Attempts were made to correlate the computer simulation results with laboratory test data. The test data was not a simulation of a 'real' situation, but rather an idealized situation, with no air flow out of or into the chase. The test structure was built to conform to the CAN/ULC S605-M87 standard. Thermocouples were placed on the inside of the insulated enclosure surrounding the flue. The edges of the enclosure were sealed with tape. The enclosure was eight feet in height.

The computer model was adjusted to reflect the test conditions. Insulation was added to the chase, and the results of the simulation were compared to the laboratory test data. The model was refined until the temperatures in the inside of the structure were similar to the temperatures recorded in the laboratory test. The FLUESIM results varied from the laboratory test data by less than 1% along the height of the flue.

A base case model was created for the simulation runs based using the results of the laboratory data comparison.

Furnace Cycling

Furnace cycling was simulated by running the model for lengths of 240 seconds, 540 seconds and 840 seconds. The length of the cycle influenced the results, the longer the cycle, the higher the temperatures in the flue. Comparing Table 8 and Table 9 shows that the temperatures in the flue increase as the cycle lengthens. (F1 through F9 indicate the vertical flue elements, F1 is at the bottom. Figure 3 shows the flue elements and calculation points.)

Table 8: Short Cycle Temperature Regime

Base Case - No Insulation, Tight Chase, Time = 240s	F1	F2	F3	F4	F5	F6	F7	F8	F9
Flue Gas Temperature (°C)	74.6	72.3	70.0	67.9	65.8	63.8	61.9	60.1	58.5
Inner Liner (°C)	45.9	55.1	53.5	52.0	50.6	49.2	48.0	46.8	46.5
Insulation or Structure (°C)	n/a	23.1	22.9	22.7	22.5	22.2	22.2	22.0	25.0
Outer Structure (°C)	n/a	1.3	1.3	1.4	1.3	1.3	1.3	1.3	7.9

Table 9: Long Cycle Temperature Regime

Base Case - No Insulation, Tight Chase, Time = 840s	F1	F2	F3	F4	F5	F6	F7	F8	F9
Flue Gas Temperature (°C)	81.4	79.6	78.0	76.3	74.7	73.1	71.5	70.0	68.6
Inner Liner (°C)	53.9	66.8	65.3	63.9	62.5	61.2	59.8	58.5	58.2
Insulation or Structure (°C)	n/a	31.4	30.7	30.1	29.4	28.8	28.1	27.5	30.0
Outer Structure (°C)	n/a	3.9	3.8	3.7	3.7	3.6	3.6	3.5	7.8

Insulation

The difference in insulation levels resulted in a slight difference in the temperature regimes in the chase. A comparison can be made between a base case, with no insulation, and a chase with RSI 3.5 insulation in the walls of the chase. Both runs had the furnace cycle for 540 seconds, and the chases are considered tight.

Table 10: Base Case Temperature Regime (540 seconds)

Base Case - No Insulation, Tight Chase, Time = 540s	F1	F2	F3	F4	F5	F6	F7	F8	F9
Flue Gas Temperature (°C)	80.8	78.9	77.0	75.2	73.5	71.7	70.0	68.4	66.9
Inner Liner (°C)	53.2	64.9	63.3	61.8	60.3	58.9	57.5	56.1	55.8
Insulation or Structure (°C)	n/a	28.4	27.8	27.2	26.6	26.0	25.5	24.9	27.9
Outer Structure (°C)	n/a	2.6	2.6	2.5	2.5	2.5	2.5	2.4	7.8

Table 11: RSI 3.5 Temperature Regime (540 seconds)

RSI 3.5 Insulation, Tight Chase, Time = 540s	F1	F2	F3	F4	F5	F6	F7	F8	F9
Flue Gas Temperature (°C)	80.7	78.9	77.1	75.3	73.6	71.8	70.2	68.6	67.1
Inner Liner (°C)	53.2	65.1	63.6	62.1	60.6	59.2	57.8	56.4	56.1
Insulation or Structure (°C)	n/a	29.3	28.6	28.0	27.4	26.8	26.3	25.7	28.6
Outer Structure (°C)	n/a	1.3	1.3	1.3	1.3	1.3	1.3	1.3	6.7

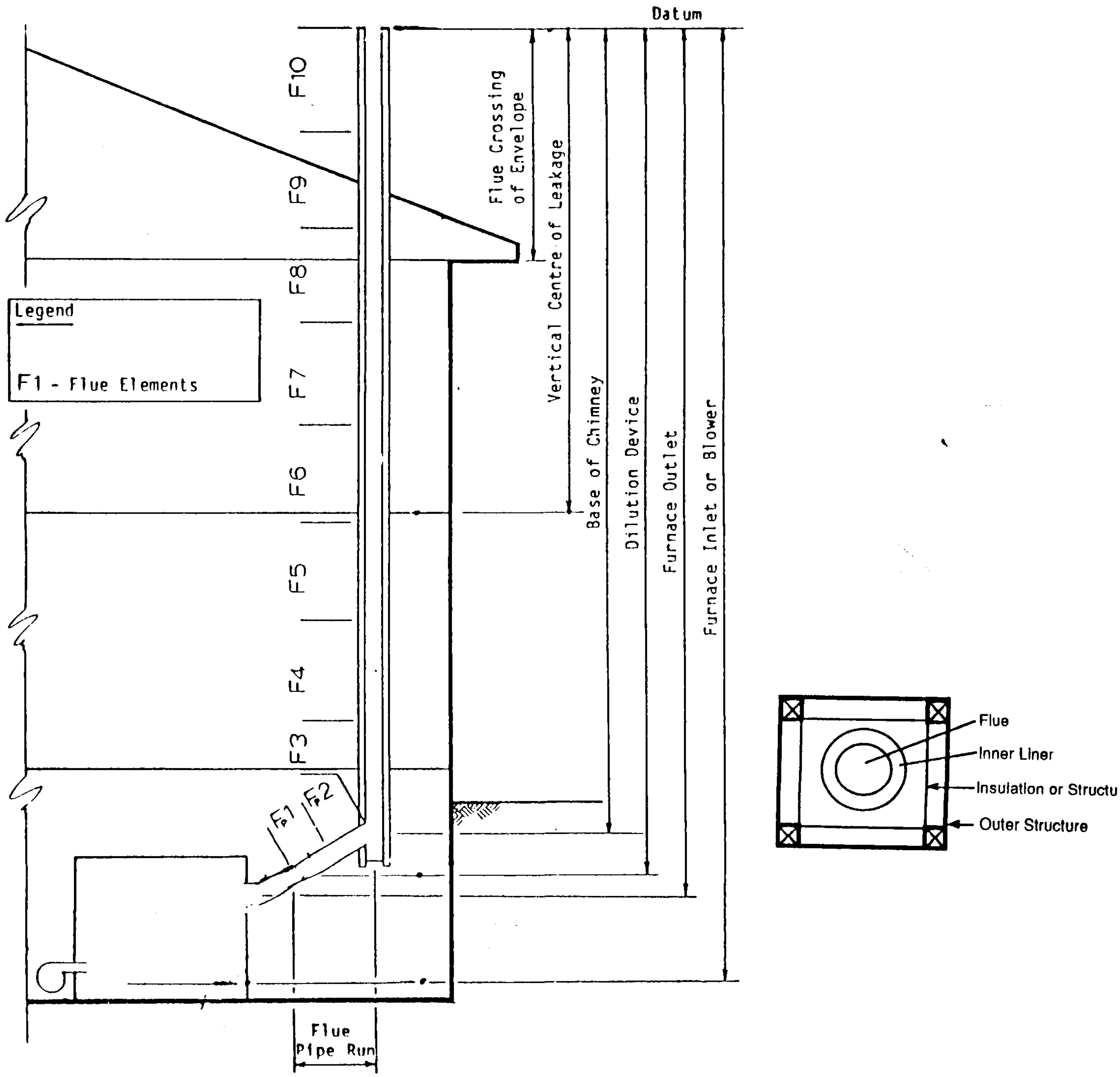


Figure 3: FLUESIM Flue Element Locations

A comparison of Tables 10 and 11 shows a slight increase in the temperatures inside the chase, and a decrease outside of the chase, both due to the increased level of chase insulation.

Chase Air Infiltration

Three different approaches to determining the effect of varying chase air infiltration rates were investigated. This section contains the results of these approaches.

Approach 1: FLUESIM House ELA

This approach turned out to be invalid because the change in the house ELA affected the furnace combustion efficiency. Varying the air leakage of just the flue chase should not change the flame temperature or exit temperature of the furnace.

Approach 2: FLUESIM Code Modifications

This approach was dropped as code modifications are outside the scope of this project.

Approach 3: FLUESIM Heat Loss Factors & Air Leakage Rate Estimates

The air infiltration rate of the chase was modelled by changing the heat loss factor between the chase enclosure and the surrounding. The assumption here is that a heat loss factor can be derived that represents both conduction losses and heat loss due to air infiltration.

Tables 12 and 13 show the results when the heat loss factor was set to the lowest and the highest possible values (allowed in FLUESIM) for a 1800 second (30 minute) furnace cycle time.

Table 12: Minimum Heat Loss Factor at 1800 Seconds

HLF 3-Surr. = .01 W/m^2•C, Time = 1800 seconds	F1	F2	F3	F4	F5	F6	F7	F8	F9
Flue Gas Temperature (°C)	86.5	85.5	84.1	82.8	81.5	80.2	78.9	77.7	76.5
Inner Liner (°C)	71.2	77.2	73.7	72.5	71.3	70.1	69.0	67.9	66.8
Insulation or Structure (°C)	19.0	49.2	38.2	37.5	36.9	36.2	35.6	35.0	34.3
Outer Structure (°C)	19.0	26.5	9.6	9.4	9.2	8.9	8.7	8.5	8.3

Table 13: Maximum Heat Loss Factor at 1800 Seconds

HLF 3-Surr. = 200 W/m²•C, Time = 1800 seconds	F1	F2	F3	F4	F5	F6	F7	F8	F9
Flue Gas Temperature (°C)	87.0	85.8	84.3	82.8	81.4	79.9	78.5	77.1	75.8
Inner Liner (°C)	71.4	76.5	72.5	71.3	80.0	68.8	67.6	66.4	65.2
Insulation or Structure (°C)	19.0	45.5	33.4	32.8	32.3	31.7	31.1	30.6	30.0
Outer Structure (°C)	19.0	19.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Comparing the results at the two extremes for a furnace cycle time of 1800 seconds, shows that FLUESIM reports a maximum temperature difference of 9.1°C at flue element 3 (F3 is at the base of the flue inside the chase). Therefore, the worst case temperature rise between an uninsulated, leaky flue and a super-insulated, tight flue is approximately 9°C for the conditions evaluated.

Note that the surrounding temperature (i.e., the outside air) was assumed to be at 0°C for these runs. Varying the outside air temperature affects the outer structure temperature itself but does not substantially change the difference in the outer structure temperature between the maximum and minimum heat loss factors. Trial runs were done for -5°C and +5°C to evaluate the sensitivity of results to the surrounding chase temperature and the results stayed relatively constant at a 9°C temperature rise.

The furnace cycle time of 1800 seconds should be the maximum period that a properly sized furnace would operate at these conditions. For furnace cycle times less than 1800 seconds, the temperature difference between the maximum and minimum outside heat loss factor drops to less than 9°C (e.g., 4.5°C at 240 seconds).

The total heat loss out of the flue can be estimated using the FLUESIM flue gas temperatures, mass flow rate, and gas properties, as follows.

$$q_{loss} = m \cdot C_p \cdot dT$$

For the maximum heat loss factor (200 W/m²•C):

m = mass flow rate = 0.056 kg/sec
C_p = specific heat of the flue gas = 1.035 KJ/Kg•C
dT = gas temperature difference between locations F9 and F3 = 84.3°C - 75.8°C = 8.5°C

$$q_{loss} = 493 \text{ W}$$

For the minimum heat loss factor (0.01 $W/m^2{\bullet}C$):

m = mass flow rate = 0.056 kg/sec
C_p = specific heat of the flue gas = 1.035 KJ/Kg•C
dT = gas temperature difference between F9 and F3 = 84.1°C - 76.5°C
= 7.6°C

q_{loss} = 441 W

This implies that an average of 441 W is required to bring the flue pipe, the enclosure air space, and the flue enclosure material to steady state conditions from their initial conditions. In other words, at an enclosure U of 0.01 $W/m^{2\circ}C$ (100 RSI), there should be virtually no losses to the surroundings.

The difference, 52 W (493 - 441, or 11% of the maximum heat loss), should represent the total envelope losses at the maximum heat loss factor of 200 $W/m^{2\circ}C$ (0.005 RSI). Although we want this number to represent both conduction losses and infiltration losses, it clearly does not include the effects of infiltration.

As a reality check on the validity of 52 W representing the infiltration and conduction losses from the chase enclosure, the infiltration load can be estimated by approximating the infiltration rate of outside air into the chase. The infiltration rate can be estimated using the average of the field measured ELAs and the LBL method for estimating the natural infiltration rate (1993 ASHRAE Fundamentals p.23.19):

$$Q = L\,(A{\bullet}dT + B{\bullet}v^2)^{0.5}$$

Where:
Q = natural infiltration air flow rate in L/s
L = effective leakage area at 4 Pa = 341 cm^2 * $(4^{0.7188}/10^{0.7188})$ = 177 cm^2
A = stack coefficient for a 2 storey house = 0.00029 $(L/s)^2(cm)^{-4}(°C)^{-1}$
dT = average temperature difference across chase envelope (unknown)
B = wind coefficient for moderate local shielding (code 3) for a 2 storey house
= 0.000231 $(L/s)^2(cm)^{-4}(m/s)^{-2}$
v = average wind speed = 0 m/s

If we assume that the average temperature of the chase enclosure air is halfway between the average exterior flue surface temperature (0.5°C) and the average flue enclosure surface temperature (31.7°C), then the average chase air temperature is approximately 15.6°C. That would make dT=15.6°C (0°C outside air temperature), and the infiltration air flow rate would be:

$$Q = 12 \text{ L/s}$$

The infiltration load would be:

$$q_{inf} = (Q \cdot rho \cdot C_p \cdot dT)$$
$$q_{inf} = 194 \text{ W}$$

As the infiltration load is substantially higher than 52 W remainder, it is clear that FLUESIM ignores air leakage into the chase enclosure. Approximately 90% of the flue heat loss is stored in the flue pipe, the chase air space, and the chase enclosure material, while slightly over 10% is conducted through the enclosure material to the outside air.

Therefore, the 9°C flue enclosure temperature rise is most certainly a worst case scenario. If the infiltration load estimate made above is reasonable, all of the heat transfer from the flue pipe would be dissipated by exchange with the outside air in a flue with an ELA of near those tested in this project (341 cm^2). This means that the enclosure insulation is relatively ineffective at controlling heat loss through the enclosure material since the predominant mode of heat loss is infiltration of outside air into the chase.

4. CONCLUSIONS

4.1 Interior Chimney Clearances

The Interior Chimney Clearances study has shown that temperatures increase in the joist clearance space as the space is reduced. Placing insulation in the clearance space, increased the temperature at the chimney outer surface and did not reduce the temperature by a significant amount at the joist surface.

Increasing the clearance between the outer surface of the chimney and the joist lowered the average temperature in the joist box when the joist box was sealed on the top and on the bottom firestops.

The investigations on Interior Chimney Clearances was not intended to be a standards tests, however as the test rig was built roughly in accordance with the CAN/ULC S629-M87 standard, comments on the results are valid. The temperatures on combustibles as measured in the second, third, fourth and seventh tests exceed the maximum temperature rise of 65°C that is specified in Section 6.3, Test No. 3 of the CAN/ULC S629-M87 standard.

4.2 Exterior B Vent Chases

A great deal of time and effort was invested to find and persuade homeowners to allow the testing of their chases for air leakage. Testing was only performed on chases that allowed a reasonable means of accessing the interior of the chase and did not show any external cosmetic changes as a result of the testing.

A small sample of existing chases were tested, with the CMHC Duct Test Rig. Equivalent leakage areas were calculated from the data obtained. The average ELA of the chases tested is 341 cm^2 and the average flow exponent is 0.7188. The average is a first order estimate only and should not be used as a representative value.

Normalizing the equivalent leakage areas obtained provides a means of comparing the results with typical values for other structures such as houses. The values are large compared to the results obtained from air tightness testing of houses. Typical NLA values for houses[2] range from 0.44 to 6.77 cm^2/m^2, while the range obtained in this

[2] **Field Testing of House Characteristics**, 1993, by Scanada Consultants Limited for CMHC Research

study was between 12 and 35 cm^2/m^2.

Modelling the affect of flue enclosure insulation and air infiltration rates on temperature changes in an exterior chase is a difficult task. The computer simulation results show that FLUESIM models do not provide a good indication of the functioning of exterior chases. At fault is the assumption that FLUESIM can be extended, as is, to model various heat transfer scenarios in flue enclosures when it was designed to simulate the furnace-flue system only.

A simple hand calculation was done that showed that the FLUESIM estimate of a temperature rise of the flue enclosure surface temperature over the outside air temperature of 9°C is an over-estimate and should be considered a worst case approximation for a well sealed flue enclosure.

The natural winter air infiltration rate of the flues tested (ignoring the effect of wind) is a more significant heat loss component than the enclosure insulation level. The ambient air temperature in the chase, and the resulting flue enclosure surface temperature, are thought to depend more upon the infiltration rate, the furnace cycling time, and the initial air and enclosure temperatures than the insulation level of the enclosure.

The heat transfer dynamics of the furnace/flue/chase are complicated and the simple hand calculations cannot fully represent this system. However, without the benefit of a valid computer simulation model for the flue enclosure, the work done in this project represents a reasonable estimate.