RESEARCH REPORT

GARAGE PERFORMANCE TESTING
FINAL REPORT

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Garage Performance Testing

Final Report

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Canada Mortgage and Housing Corporation

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Abstract

The focus of this study was to:
1) Establish the range and profile of airtightness in the garage-to-house interfaces in regions across Canada.
2) Determine the implications of garage-to-house air leakage on house indoor air quality.
3) Propose and test solutions for reducing contaminant transfer between garages and houses.

Forty-two houses with attached garages were tested to assess the leakage characteristics of the house to garage interface. On average 10 to 13% of house leakage occurs through the interface. Based on CONTAM modelling using a cold start and a hot soak test, it was found that ten of the 42 houses had elevated pollutant levels indoors resulting from garage-to house air leakage.

Three remediation strategies were tested and modelled, including
1. Tightening the garage-to-house interface,
2. Installation of a passive air grille from the garage to the exterior, and
3. Installation of an exhaust fan in the garage.

All strategies were found to reduce peak concentrations of pollutants in the house.

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1.1 Project Objectives

The Objectives of this research are to:

1. Establish the range and profile of airtightness in the garage-to-house interfaces in regions across Canada.
2. Determine the implications of garage-to-house air leakage on house indoor air quality.
3. Propose and test solutions for reducing contaminant transfer between garages and houses.

1.2 Methodology

A series of air tests were completed on forty-two homes located in Vancouver, Winnipeg and Saskatoon. The houses and garages were airtightness tested, using blower doors, to determine their leakage areas. The results of these tests were used to complete CONTAM air flow modelling on each of the houses to assess the potential for contaminant transfer from the garage into the house. Remedial strategies to reduce garage-to-house leakage were tested and modelled to analyse the effectiveness of alternative approaches.

1.3 Results

1.3.1 Profile of Garage-to-House Interface Leakage Characteristics

Based on the airtightness testing completed on 42 homes with attached garages, it was found that on average, that interface leakage accounts for approximately 10% to 13% of the total house leakage area. These results are consistent with previous testing (Scanada, 1997). In total four of the 42 houses tested had interfaces where more than 25% of the house leakage occurred through the interface. Three of these houses were new row houses with the mechanical room located in the garage.

1.3.2 Extent of Houses With Interface Leakage Areas That Can Result In Negative Health Implications

The houses were modelled with CONTAM to simulate contaminant transport between the garage and the house. The same four houses that have garage-to-house interface leakage exceeding 25% exceeded recommended exposure limits for carbon monoxide (exceeding 28.5 mg/m^3 for 1 hour).

1.3.3 Solutions for Managing Contaminant Transfer

Three remediation strategies were tested, including sealing of the interface area, installation of a transfer grille and installation of an exhaust fan. All three strategies were found to reduce peak concentration of pollutants in both the garages and the houses where they were tested.

1.4 Conclusions

Based on the current analysis, the following conclusions are made:

1. Based on the airtightness testing completed on 42 homes with attached garages, it was found that on average, that interface leakage accounts for approximately 10% to 13% of the total house leakage area. These results are consistent with previous testing (Scanada, 1997).

2. If more than 25% of the house air leakage occurs through the garage, our simulations show that garage-based emissions could cause significant house indoor air quality problems. In total four of the 42 houses tested had interfaces where more than 25% of the house leakage occurred through the interface. Three of these houses were new row houses with the mechanical room located in the garage.

3. The same four houses that were found to have loose garage-to-house interfaces were found to exceed recommended exposure limits for carbon monoxide on the basis of CONTAM simulations. None of the houses modelled were found to exceed benzene exposure limits.

4. Three remediation strategies were tested. All three strategies were found to reduce peak concentration of pollutants in both the garages and the houses where they were tested.
    - Installation of a transfer grille did reduce peak pollutant concentrations in the house, however, carbon monoxide levels still exceeded guidelines within the house.
    - Air leakage sealing of the garage-to-house interface results in reduced contaminant transfer, and is the preferred approach for new homes. For the case where leaks are accessible in a retrofit situation, air sealing is also achievable.
    - When leaks are not accessible, installing an exhaust fan ranging in size from 25 L/s to 100 L/S and running it for 30 minutes helps to reduce the transfer from the garage to the house of car start-up contaminants.

5. Mechanical rooms with access through the garage should be discouraged due to high contaminant transfer potential in these dwellings.

1 Résumé

1.1 Objectifs de la recherche

La recherche avait pour objectifs :

1. D'établir le profil et l'étendue du degré d'étanchéité des interfaces garage-maison dans toutes les régions du Canada.
2. De déterminer l'incidence des fuites d'air entre les garages et les maisons sur la qualité de l'air intérieur.
3. De proposer et de mettre à l'essai des mesures correctives visant à réduire la diffusion de contaminants entre les garages attenants et les maisons.

1.2 Méthode

Une série d'essais sur l'étanchéité à l'air a été menée sur 40 maisons situées à Vancouver, à Winnipeg et à Saskatoon. Les maisons et les garages ont subi des essais d'étanchéité à l'air au moyen d'un infiltromètre en vue de déterminer l'aire de fuites totale. Les résultats de ces essais ont ensuite été utilisés dans le logiciel CONTAM pour modéliser les mouvements d'air dans chaque maison afin d'évaluer la possibilité de diffusion de contaminants depuis le garage jusqu'à la maison. Des mesures correctives visant à réduire les fuites à travers l'interface garage-maison ont ensuite été mise à l'essai et modélisées dans le but d'analyser leur efficacité.

1.3 Résultats

1.3.1 Profil des caractéristiques d'étanchéité de l'interface garage-maison

En se fondant sur les essais d'étanchéité réalisés dans 42 maisons dotées de garages attenants, on a trouvé que les fuites à travers l'interface représentent, en moyenne, environ entre 10 et 13 % de l'aire de fuites totale des maisons. Ces résultats sont compatibles avec les résultats obtenus dans d'autres études (Scanada, 1997). Au total, 4 maisons sur les 42 mises à l'essai comportaient une interface dont plus de 25 % des fuites à travers l'enveloppe de la maison se produisent à travers l'interface garage-maison. Trois des maisons étaient de nouvelles maisons en rangée dont le local technique était situé dans le garage.

1.3.2 Étendue des maisons dont l'aire de fuite de l'interface est telle qu'elle peut engendrer des répercusssions négatives sur la santé

On a modélisé les maisons à l'aide de CONTAM afin de simuler la diffusion de contaminants entre le garage et la maison. Dans les mêmes 4 maisons dont les fuites d'air de l'interface garage-maison représentaient plus de 25 % de l'aire de fuites totale, la limite d'exposition recommandée au monoxyde de carbone a été dépassée (plus de 28,5 mg/m^3 pour une heure).

1.3.3 Solutions permettant de gérer la diffusion de contaminant

Trois mesures correctives ont été mises à l'essai, dont l'étanchéisation de l'interface garage-maison, la pose d'une grille de transfert et la pose d'un ventilateur d'extraction. Les essais révèlent que les trois mesures ont diminué la teneur en contaminants tant dans les garages que dans les maisons.

1.1 Conclusions

En se fondant sur l'analyse courante, les conclusions suivantes ont été formulées :

1. Selon les résultats des essais d'étanchéité menés sur 42 maisons dotées de garages attenants, on a découvert que les fuites d'air représentent, en moyenne, de 10 % à 13 % de l'aire de fuites totale des maisons. Ces résultats cadrent avec les essais antérieurs (SCANDA, 1997).

2. Si plus de 25 % des fuites de la maison se produisent par le garage, les simulations indiquent que les émissions en provenance du garage pourraient engendrer des problèmes considérables de qualité de l'air intérieur. Au total, 4 des 42 maisons mises à l'essai comportaient des interfaces dont plus de 25 % des fuites passaient par l'interface. Trois de ces maisons étaient des maisons neuves en rangée dont le local technique donnait sur le garage.

3. Les mêmes quatre maisons, qui présentaient des interfaces garage-maison plutôt perméable, avaient des teneurs en monoxyde de carbone qui excédaient la limite d'exposition recommandée, sur la base des simulations de CONTAM. On a constaté que la limite d'exposition au benzène n'a été dépassée dans aucune des maisons modélisées.

4. Trois mesures correctrices ont fait l'objet d'études. Les travaux de recherche révèlent que toutes les mesures ont diminué la teneur de pointe en contaminants, tant dans le garage que dans la maison.

- L'installation d'une grille de transfert a réduit les concentrations de pointe de polluants à l'intérieur de la maison. Cependant, les niveaux de monoxyde de carbone dépassaient les limites précisées selon les lignes directrices.
- L'étanchéisation à l'air de l'interface garage-maison en effet réduit la quantité des contaminants transférés et constitue l'approche à privilégier lors de la construction. En ce qui a trait aux travaux de rattrapage, on peut aussi avoir recours à l'étanchéisation dans les cas où les fuites sont accessibles.
- Lorsque les aires de fuite ne sont pas accessibles, on peut faciliter la réduction du transfert des contaminants, qui résultent du démarrage d'une voiture, du garage à la maison en installant un ventilateur qui fournit de 25 à 100 L/s de capacité et en le mettant en marche pour 30 minutes.

5. Il faut éviter de situer les locaux techniques dont l'accès se fait par le garage en raison de la forte possibilité de transfert de contaminants.

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2 Introduction

Research by the Canada Mortgage and Housing Corporation (CMHC), Health Canada, and Environment Canada have shown that attached garages can transfer automotive generated pollutants to the indoor air of houses. However, the amount of contaminant transfer and the effect of proposed solutions are highly variable depending on the airtightness performance of the house, garage, and their interface.

2.1 Project Objectives

The Objectives of this research are to:

1. Establish the range and profile of airtightness in the garage-to-house interfaces in regions across Canada.
2. Determine the implications of garage-to-house air leakage on house indoor air quality.
3. Propose and test solutions for reducing contaminant transfer between garages and houses.

2.2 Report Outline

This report includes the following sections:

- Section three provides a description of the methodology used to complete the research, including testing of houses with attached garages and modelling using CONTAM air-flow modelling software,
- Section four describes the results of the testing and modelling,
- Section five provides a discussion of the results, and
- Section six presents a set of conclusions.

3 Methodology

This section provides an overview of the methodology employed for testing and modelling the houses. The methodology includes:

1. Selection of homes,
2. Testing homes,
3. Development of remediation strategies,
4. Testing remediation strategies,
5. Analysis of data, and
6. Airflow modelling of homes.

Each of these steps is described below.

3.1 House Selection

A total of 42 houses were tested in Vancouver, B.C., Saskatoon, Saskatchewan, and Winnipeg, Manitoba. Twenty of the homes tested are located in Vancouver, seven are located in Winnipeg, and fifteen are located in Saskatoon. Homes with garages were identified through personal contacts, as well as professional activity related to construction of buildings.

The homes tested in Vancouver include a range of new and existing homes. All of the new homes tested were row houses. In the Winnipeg and Saskatoon samples, all homes were single family, existing homes. A description of the test homes is presented in Table 1 to Table 3.

Configuration of garage attachment is described in terms of:

- 1 side attachment with and without living space over
- 2 side attachment with and without living space over

Typical garage attachment configurations are shown in Figure 1 to Figure 4.

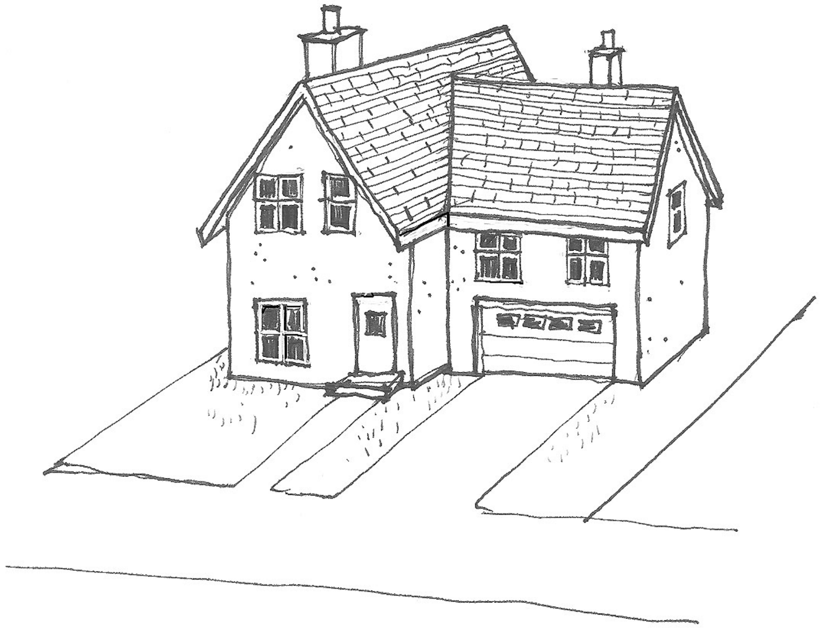

Figure 1: 1 Side Attachment With Living Space Over

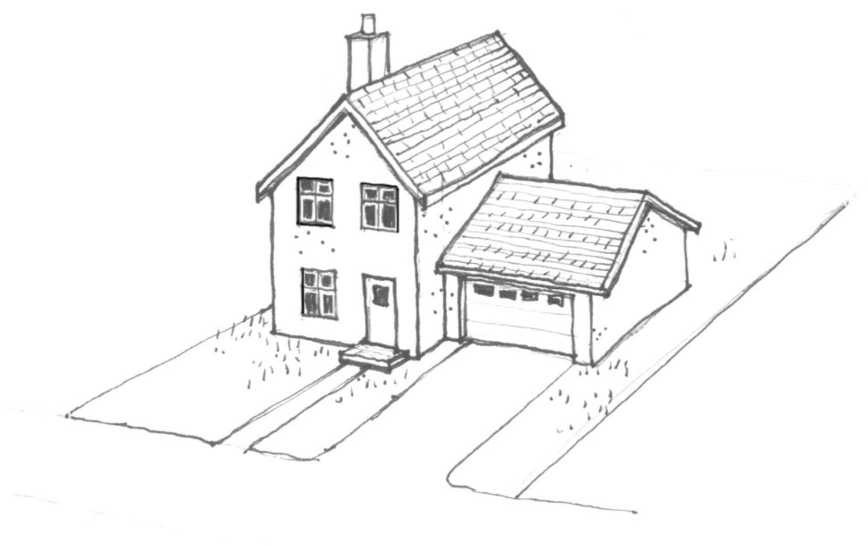

Figure 2: 1 Side Attachment Without Living Space Over

Figure 3: 2 Side Attachment With Living Space Over

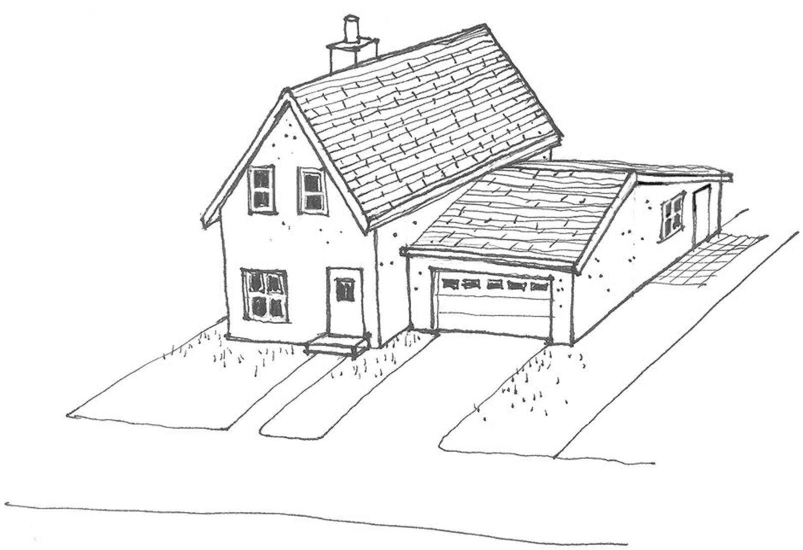

Figure 4: 2 Side Attachment Without Living Space Over

Table 1: Vancouver Area Test Houses

Unit	Detachment	Vintage	Number of Storeys	Garage Attachment	Mechanical Room Location	House		Garage		Interface Area
						Volume [Cubic Meters]	Surface Area [Square Meters]	Volume [Cubic Meters]	Surface Area [Square Meters]	[Square Meters]
VA 01	SFD	1950	2/split level	1 side	In Garage	637	553	60	103	17
VA02	SFD	1984	2	1 side and living space over	In garage	366	316	141	175	68
VA 03	SFD	1993	4 (stepped at back)	1 side and living space over	In living space	921	611	108	160	76
VA 04	Townhouse	2003	3	1 side and living space over	In garage	300	330	110	101	71
VA 05	SFD	1993	2	1 side and living space over	In garage	835	601	87	130	50
VA 06	SFD	1975	1 with crawl	1 side	In living space	377	407	112	169	8
VA 07	SFD	1997	3	1 side	In living space	449	374	48	85	13
VA 08	Townhouse	2003	3	1 side and living space over	In garage	387	311	83	126	49
VA 09	SFD	2003	3	1 side and living space over	In garage	436	333	138	174	73
VA 10	Townhouse	2003	3	1 side and living space over	In garage	272	316	113	169	72
VA 11	SFD	1980	1	2 sides	In living space	355	431	90	134	16
VA 12	SFD	1935	3	1 side and living space over	In garage	1064	832	143	186	61
VA 13	Townhouse	2003	3	1 side and living space over	In garage	332	319	129	170	70
VA 14	SFD	1995	3	1 side	In living space	1766	1413	95	139	7
VA 15	SFD	1975	2	2 sides	In living space	564	454	61	98	26
VA 16	SFD	1978	2	2 sides	In living space	711	570	88	131	57
VA 17	Townhouse	2003	3	1 side and living space over	In garage	571	416	87	129	50
VA 18	SFD	1983	3	1 side	In living space	839	671	158	186	22
VA 19	Townhouse	2003	3	1 side and living space over	In garage	487	372	84	126	49
VA 20	Townhouse	2003	3	1 side and living space over	In garage	487	372	84	126	49

Table 2: Winnipeg Area Test Houses

			Number of Storeys	Garage Attachment	Mechanical Room Location	House		Garage		Interface Area
Unit	Detachment	Vintage				Volume [Cubic Meters]	Surface Area [Square Meters]	Volume [Cubic Meters]	Surface Area [Square Meters]	[Square Meters]
WI 01	SFD	2000	1	1 side	Main Floor	540	400	125	140	25
WI 02	SFD	1974	1	2 sides	Main Floor	699	569	108	151	26
WI 03	SFD	1973	2	2 sides	Basement	646	491	145	178	36
WI 04	SFD	1975	2	2 sides	Basement	892	694	109	151	59
WI 05	SFD	1919	2	1 side and living space over	Basement	547	463	61	114	25
WI 06	SFD	1975	2	1 side	Basement	705	511	145	175	17
WI 07	SFD	1973	2	2 sides	Basement	688	538	132	166	35

Table 3: Saskatoon Area Test Houses

			Number of Storeys	Garage Attachment	Mechanical Room Location	House		Garage		Interface Area
Unit	Detachment	Vintage				Volume [Cubic Meters]	Surface Area [Square Meters]	Volume [Cubic Meters]	Surface Area [Square Meters]	[Square Meters]
Sa 01	SFD	1980	1 storey	1 side	In house	516	422	127	163	16
Sa 02	SFD	1998	2 storey	1 side with living space over	In house	862	560	118	158	30
Sa 03	SFD	1986	2 storey, split level	1 side	In house	620	486	141	171	22
Sa 04	SFD	1978	2 storey	1 side	In house	402	349	93	130	21
Sa 05	SFD	1980	2 storey, split level	1 side	In house	511	406	132	173	17
Sa 06	SFD	1978	2 storey	1 side	In house	616	491	130	166	31
Sa 07	SFD	1982	1 storey	1 side	In house	810	633	127	120	32
Sa 08	SFD	1965	2 storey	1 side	In house	631	482	301	265	15
Sa 09	SFD	1997	2 storey, split level	1 side	In house	660	478	116	151	16
Sa 10	SFD	2000	3 storey	1 side	In house	829	588	237	207	21
Sa 11	SFD	1967	1 storey	1 side	In house	611	502	168	147	21
Sa 12	SFD	1977	1 storey	1 side	In house	513	432	125	95	21
Sa 13	SFD	1960	2 storey	1 side	In house	515	481	158	184	22
Sa 14	SFD	1985	1 storey	1 side	In house	711	536	112	154	25
Sa 15	SFD	2001	1 storey	1 side	In house	564	426	123	159	14

3.2 Air Leakage Testing

Testing of the Vancouver and Winnipeg homes was completed in the winter of 2003. Testing of the Saskatoon area homes was completed in the late summer of 2003.

Testing included the following tasks:

1. Set-up,
2. Testing,
3. Description of house, and
4. Return to original configuration.

3.2.1 Set-up

Set-up included installation of door fans for testing, setting up the house in accordance with the CGSB 149.10-M86, *Determination Of The Airtightness Of Building Envelopes By The Fan Depressurization Method* standard, including closing windows, filling plumbing stacks, turning mechanical equipment to the pilot setting, and closing all dampers. The house was tested "as occupied", with intentional openings (including the combustion make up air duct and furnace flues) not sealed. This is consistent with the procedure used in the Scanada report and provides a more realistic characterization of the house leakage for the purpose of assessing pollutant transfer risk.

3.2.2 Testing

Testing included a series of airtightness tests, including:

1. House Test,
2. Garage Test, and
3. Balanced Test.

Airtightness tests were conducted in accordance with CGSB 149.10-M86. When completing the House Test, the garage door was left open to eliminate possible interference of the garage airtightness. When conducting the Garage Test, the front door of the house was left open to eliminate the house airtightness from results. When the Balanced Test was conducted, the house and the garage were in the "closed" configuration according to CGSB. Test equipment is shown in Figure 5.

In most cases, the garage had a side door or window which opened to the exterior. This permitted installation of the garage fan directly into an exterior door. In the cases where no man door or window was present, a garage door opened to the interior of the house. In these cases, flex duct was used during the Balanced Test from the garage to a nearby window or door during pressure equalisation. Flex duct equipment is shown in Figure 6.

A number of the homes tested in Vancouver were row style. This added a level of complexity to the testing, as it was necessary to eliminate party wall leakage. This was done by testing end units and by using a third door fan to balance pressure across the party wall.

3.2.3 Description of House

A physical description of each house was obtained, including:

- Floor plan, including,
    - Key dimensions,
    - Location of garage,
    - Size and location of major openings,
- Sections, and
- Digital images.

3.2.4 Return to Original Configuration

Once the testing was completed, the homes were returned to their original configuration. All dampers, windows and mechanical equipment was returned to the original settings and pilot lights were checked. Finally, all mechanical equipment was checked for proper operation.

Figure 5: Fan Door Apparatus

Figure 6: Flex Duct Configuration for Balanced Test

3.3 Develop Three Remediation Strategies

At the proposal stage, a number of potential remediation strategies were identified, including:

1) Increasing the airtightness of the garage-to-house interface by:
   a) Sealing existing interface walls,
   b) Comparing airtight drywall (ADA) versus poly air barrier, and
   c) Sealing garage ceiling leakage.
2) Decreasing the airtightness of garages (with the exception of the garage-to-house interface) so that contaminant concentration in the garage decreases more quickly over time, resulting in lower contaminant transfer to the house. Examples of potential strategies include adding a vent grille to the exterior wall of unheated garages.

3) Removing part (or all) of the contaminant from the garage with an exhaust fan to decrease the concentration of contaminant in the garage, resulting in reduced transfer to the house.

Due to the configuration of the houses tested, the strategies tested include:

1. Air sealing of the garage-to-house interface,
2. Installation of a transfer grille in the garage, and
3. Installation of a garage exhaust fan.

3.4 Test Remediation Strategies

Testing of remediation strategies was conducted in three Vancouver houses, while house air tests were being conducted. The remediation tests were conducted using the following procedure:

1. To simulate the impact of reduced interface leakage, the interface was temporarily sealed.
2. To simulate the impact of a transfer grille one house was tested with the transfer grille blocked and re-tested with it open. Results were then modeled with CONTAM software.
3. To simulate the impact of an exhaust fan, one house was tested with the fan sealed and re-tested with it open. The fan flow rate was obtained and the presence of the fan was modelled as part of the CONTAM simulations.

3.5 Analysis of Data

The following quantities were calculated for each test house:

- Volume for house and garage,
- Surface area for house and garage, and
- Interface area.

Air leakage data was analysed to obtain the following quantities:

- House leakage in terms of equivalent leakage area (ELA), air change at 50 Pascals (AC/H@50), and normalized leakage area (NLA),
- Garage leakage in terms of ELA, AC/H@50 and NLA, and
- Garage interface leakage in terms of ELA and NLA.

In accordance with CGSB requirements, the fan constant C, flow exponent, n, and the correlation co-efficient were also recorded. The garage-to house interface area was included in surface area calculations when determining the house NLA and the garage NLA. Airtightness test results are provided in the appendix and summarised in the next chapter.

3.6 Airflow Modelling of Homes

Each house was modelled using CONTAM airflow modelling[1] software to simulate airflow through the garage-to-house interface. CONTAM is a multi-zone indoor air quality and ventilation analysis computer program designed to model airflows: infiltration, exfiltration, and room-to-room airflows in building systems driven by mechanical means, wind pressures acting on the exterior of the building, and buoyancy effects induced by the indoor and outdoor air temperature difference.

3.6.1 Description of the Modelling Procedure

A series of archetypal dwelling units were developed for the purpose of modelling contaminant transfer. The archetypes were created to provide a simplified version of the actual buildings tested. To model a specific building, the archetype that closest represented the actual building form was used.

To develop a model for each house, geometric data and airtightness characteristics were applied to the archetype that closest matched the actual house. Surface areas, interface areas, numbers of floors, volumes, interface leakage areas and component leakage areas were adjusted to correspond to the air test results of the actual homes sampled. Initial simulation runs were completed to calibrate model results and airtightness tests results. The garage was modelled to obtain the correct airtightness. Next the house airtightness was adjusted to correspond to the results of the house air tightness test. Finally, the interface leakage area was calibrated to test data.

Simulations were completed assuming steady state weather conditions summarised in Table 4.

Table 4: Weather Conditions During Simulations

Parameter	Value
Outdoor Temperature	10 Degrees Celsius
Pressure	101325 Pascals
Wind Speed	0 Km/h
Test Duration	4 hours

For the purpose of assessing health risk thresholds, two standard tests were simulated on each house, including a cold start and hot soak test.

3.6.2 Cold Start Emissions

A Cold Start test was simulated in CONTAM. In this test, 49.5 g of carbon monoxide was released over a period of 90 seconds[2]. Concentrations of carbon monoxide within the garage and living spaces of the dwelling were modelled in five-minute increments for 240 minutes. The acceptable short-term exposure range (ASTER) of carbon monoxide in indoor air for a one-hour concentration is 28.5 milligrams per cubic meter (25 ppm).[3]

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[1] National Institute of Standards and Technology
[2] Emission generation rates are based on Environment Canada procedures, Personal Communication Carmela Grande.
[3] Health Canada Exposure Guidelines for Residential Indoor Air Quality, 1989

3.6.3 Hot Soak Test

A hot soak test was simulated by releasing 10.5 mg of benzene, based on an emissions profile defined in Figure 7[4]. Ambient benzene concentrations were assumed to be 1.13 micrograms per cubic meter[5]. Chronic health effects are possible above a benchmark of 80 ug/m^3.[6] Concentrations of benzene within the garage and living space were modelled in five-minute increments for 240 minutes.

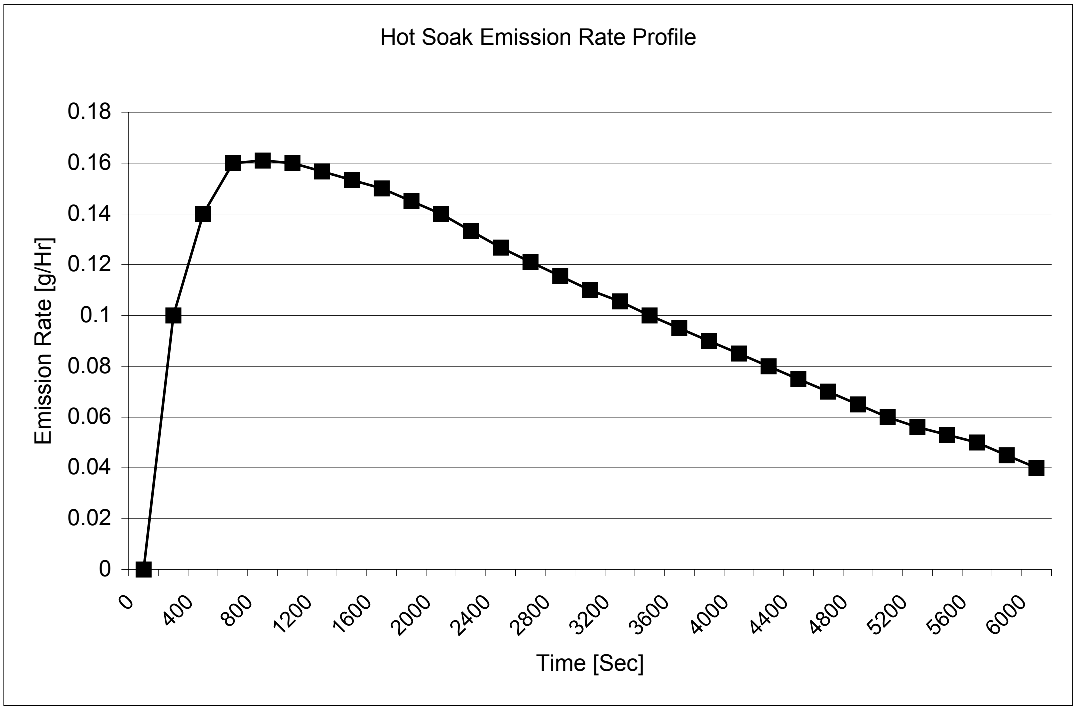

Figure 7: Hot Soak Test Emission Profile

3.6.4 Remedial Strategy Modelling

The three remediation strategies were modelled using CONTAM. A description of the modelling results is presented in the next section.

[4] Emission generation rates are based on Environment Canada procedures, Personal Communication Carmela Grande
[5] US EPA.
[6] http://www.osha-slc.gov/dts/chemicalsampling/data/CH_220100.html

4 Results

4.1 Airtightness Test Results

Results of the airtightness tests for each house are presented in Table 5 through Table 7, with summaries presented in Table 8 through Table 11. Results from a previous CMHC investigation of garage interface air leakage characteristics are also included (Scanada [1997]).

As can be seen,

- The average airtightness of homes is 8.4 AC/H, 3.7AC/H, 3.1 AC/H and 4.8 AC/H for the Vancouver, Winnipeg, Saskatoon and Ottawa sample houses, respectively.
- Garage air leakage rates, on average, are 37AC/H, 18 AC/H, 17 AC/H and 47 AC/H for the Vancouver, Winnipeg, Saskatoon and Ottawa sample houses, respectively.
- The Garage-to-House interface leakage is on average, 0.8AC/H, 0.4 AC/H, 0.3 AC/H and 0.7 AC/H for the Vancouver, Winnipeg, Saskatoon and Ottawa sample houses, respectively.
- The house leakage through the garage-to-house interface accounts for 10% to 13% of the leakage in the sample houses.

4.1.1 Observations of Test Results

Observations from the data include:

1. Houses in the Vancouver sample houses are significantly less airtight than the sample houses in other regions.

2. Garages in the Winnipeg and Saskatoon sample houses are significantly more airtight than the Vancouver and Ottawa sample houses.

3. The garage-to-house interface leakage of houses in Vancouver are significantly higher than the houses located in Winnipeg and Saskatoon. The area of the garage-to-house interface is also larger, resulting in similar NLAs the three regions.

4. In general, the average garage house interface is consistent across sample houses and regions. However, a number of the Vancouver sample houses have garage-to house interface leakage areas that are significantly above the average.

5. The Vancouver houses with the largest interface leakage characteristics had furnaces, and the furnaces were located in a mechanical room accessed through the garage[7]. Primary leakage paths included:
   - Poor weather stripping of the mechanical room doors,
   - Unintentional leakage of the return air ducts to furnaces causing depressurisation of the mechanical room, and resulting in entrainment of garage air and air transfer to the living space,
   - Excessive sized holes for penetrations between the mechanical room and living space.

6. The amount of air leakage through the garage to house interface was calculated on the basis of air change rates and equivalent leakage areas. In most houses, the amount was similar. For some houses, for example VA 13, Wi 03, Wi 04 and Sa 03, the estimates varied by as much as 15%. While not clear, it is likely wind effects causing the discrepancy in the two calculations.

7. Four houses (Va 02, Va 04, Va08 and Va10) had envelopes where more than 25% of the air leakage was occurring through the garage-to house interface (measured on the basis of ELA). No houses in the Winnipeg or Saskatoon sample had these elevated levels of leakage through the garage-to-house interface. Three out of a sample of twenty-five houses in the Scanada report had garage-to house interface leakages that exceed 25%.

[7] In general, locating mechanical rooms in the garage is considered poor practice. Test results from this study validate this assumption.

Table 5: Vancouver Airtightness Tests Results

	House			Garage			Airtightness of Garage-to-House Interface				
Code	Ac/h@50 Pa	ELA (cm^2)	NLA (cm^2/m^2)	Ac/h@50 Pa	ELA (cm^2)	NLA (cm^2/m^2)	Ac/h@50 Pa	ELA (cm^2)	NLA (cm^2/m^2)	Percentage of air leakage	Percentage of air leakage
										AC/H	ELA (cm^2)
VA 01	9.7	2,685	4.9	92.7	2,595	187.0	0.3	3	0.2	3%	0%
VA02	5.4	1,389	2.7	42.9	2,575	14.7	1.8	387	5.7	**33%**	**28%**
VA 03	8.0	2,951	4.5	18.5	922	5.8	0.8	93	1.2	10%	3%
VA 04	5.5	620	1.9	15.2	688	6.8	1.2	254	3.6	**26%**	**46%**
VA 05	3.5	1,196	2.0	34.7	1,132	8.7	0.3	98	2.0	7%	8%
VA 06	10.6	1,630	3.9	112.0	6,500	38.3	0.3	21	2.6	4%	1%
VA 07	5.5	995	2.7	28.0	499	5.9	0.2	52	4.0	4%	5%
VA 08	7.1	1,150	3.7	20.4	675	5.4	3.7	588	12.0	**60%**	**58%**
VA 09	5.2	830	2.5	17.7	916	5.3	1.1	40	0.5	21%	5%
VA 10	9.0	1,091	3.5	19.7	997	5.8	1.8	222	3.1	**27%**	**28%**
VA 11	15.9	2,378	5.5	36.5	1,127	8.4	0.3	123	7.7	2%	5%
VA 12	10.2	5,292	6.4	68.0	5,601	30.1	0.1	227	3.7	1%	4%
VA 13	9.9	1,403	4.4	15.3	896	4.9	2.7	186	2.7	29%	14%
VA 14	5.2	3,816	2.7	21.2	869	6.3	0.3	57	8.1	5%	2%
VA 15	10.9	3,018	6.7	27.7	856	8.7	0.4	219	8.4	4%	7%
VA 15 *	10.9	2,937	6.5	27.7	856	8.7	0.3	116	4.5	3%	4%
VA 16	11.7	3,735	6.3	34.0	1,122	8.6	0.5	8	0.1	4%	0%
VA 17	7.1	1,729	4.2	44.3	1,330	10.3	0.1	148	2.9	1%	9%
VA 18	12.4	2,697	8.5	30.5	1,660	8.9	0.0	30	1.4	0%	5%
VA 19	5.4	1,025	2.8	37.5	653	5.2	0.6	36	0.7	14%	4%
VA 20	4.4	915	2.5	24.5	847	6.7	0.2	59	1.2	5%	7%
Average	**8.3**	**2,071**	**4.2**	**36.6**	**1,586**	**18.6**	**0.8**	**134**	**3.5**	**13%**	**12%**

Table 6: Winnipeg Airtightness Tests Results

	House			Garage			Airtightness of Garage-to-House Interface				
Code	Ac/h@50 Pa	ELA (cm^2)	NLA (cm^2/m^2)	Ac/h@50 Pa	ELA (cm^2)	NLA (cm^2/m^2)	Ac/h@50 Pa	ELA (cm^2)	NLA (cm^2/m^2)	Percentage of air leakage	Percentage of air leakage
										AC/H	ELA (cm^2)
WI 01	3.0	741	1.8	25.9	1,206	8.6	0.3	19	0.8	10%	3%
WI 02	2.4	545	1.0	6.4	86	0.6	0.1	75	2.9	5%	14%
WI 03	3.5	852	1.7	14.8	907	5.0	0.6	200	5.6	16%	24%
WI 04	1.4	429	0.6	10.3	461	3.1	0.2	101	1.7	17%	24%
WI 05	9.0	1,497	2.9	44.0	1,110	9.6	1.0	143	5.4	11%	10%
WI 06	3.3	948	1.8	10.7	540	3.1	0.1	74	4.4	4%	8%
WI 07	3.2	811	1.5	17.1	890	5.4	0.2	70	2.0	7%	9%
Average	**3.7**	**831.9**	**1.6**	**18.4**	**742.9**	**5.0**	**0.4**	**97.4**	**3.2**	**10%**	**13%**

Table 7: Saskatchewan Airtightness Tests Results

	House			Garage			Airtightness of Garage-to-House Interface				
Code	Ac/h@50 Pa	ELA (cm^2)	NLA (cm^2/m^2)	Ac/h@50 Pa	ELA (cm^2)	NLA (cm^2/m^2)	Ac/h@50 Pa	ELA (cm^2)	NLA (cm^2/m^2)	Percentage of air leakage	Percentage of air leakage
										AC/H	ELA (cm^2)
Sa 01	3.7	728	1.7	20.8	886	5.4	0.2	69	4.4	5%	10%
Sa 02	3.9	1,370	2.5	8.0	349	2.2	1.0	269	9.1	25%	20%
Sa 03	2.5	622	1.3	7.7	354	2.1	0.2	119	5.5	8%	19%
Sa 04	3.7	540	1.6	18.4	615	4.7	0. 8	116	5.6	21%	22%
Sa 05	2.6	531	1.3	6.7	241	1.4	0.1	28	1.6	5%	5%
Sa 06	4.4	1,154	2.4	6.5	261	1.6	0.2	66	2.1	5%	6%
Sa 07	2.3	779	1.2	4.5	177	1.5	0.1	48	1.5	5%	6%
Sa 08	4.1	1,126	2.3	45.8	6,366	21.1	0.5	11	0.7	12%	1%
Sa 09	1.7	454	1.0	13.9	597	4.0	0.2	37	2.4	10%	8%
Sa 10	1.5	539	0.9	2.5	233	1.1	0.1	24	1.2	7%	5%
Sa 11	3.7	847	1.7	6.6	442	3.0	0.2	41	2.0	4%	5%
Sa 12	3.0	601	1.4	47.1	2,081	16.6	0.5	89	4.2	17%	15%
Sa 13	4.1	810	1.7	48.3	3,343	18.2	0.7	160	7.2	18%	20%
Sa 14	3.2	977	1.8	5.9	199	1.3	0.1	27	1.1	4%	3%
Sa 15	1.9	403	1.0	8.0	384	2.4	0.2	35	2.5	11%	9%
Average	**3.1**	**765**	**1.6**	**16.7**	**1,102**	**5.8**	**0.3**	**76**	**3.4**	**10%**	**10%**

Table 8: Summary of House Airtightness Test Results [AC/H@50]

	Minimum	Maximum	Average
Vancouver Sample	3.5	16	8.4
Winnipeg Sample	1.4	9.0	3.7
Saskatchewan Sample	1.5	4.4	3.1
Ottawa Sample (Scanada)	2.8	8.1	4.8

Table 9: Summary of Garage Airtightness Test Results [AC/H@50]

	Minimum	Maximum	Average
Vancouver Sample	15	112	37
Winnipeg Sample	6.4	44	18
Saskatchewan Sample	2.5	48	17
Ottawa Sample (Scanada)	11	97	47

Table 10: Summary of Garage-to-House Interface Airtightness Test Results [AC/H@50]

	Minimum	Maximum	Average
Vancouver Sample	0	3.7	0.8
Winnipeg Sample	0.1	1.0	0.4
Saskatchewan Sample	0.1	1.0	0.3
Ottawa Sample (Scanada)	0	2.0	0.7

Table 11: Summary of House Leakage occurring Through Garage [% of total house leakage area through interface Based on ELA]

	Minimum	Maximum	Average
Vancouver Sample	0%	58%	12%
Winnipeg Sample	3%	24%	13%
Saskatchewan Sample	1%	22%	10 %
Ottawa Sample (Scanada)	1%	43%	13%

4.1.2 Summary of Interface Airtightness Test Results

Based on the airtightness testing completed on 42 homes with attached garages, it was found that on average, that interface leakage accounts for approximately 10% to 13% of the total house leakage area. These results are consistent with previous testing (Scanada, 1997). In total four of the 42 houses tested had interfaces where more than 25% of the house leakage occurred through the interface. It should be emphasized that three of these houses (Va 04, Va 08, Va 10) were new row houses with the mechanical room located in the garage. Therefore, it is suggested that code officials review the requirements for placing mechanical rooms inside attached garages. The Scanada report identified three out of a sample of 25 houses where more than 25% of the house leakage occurred through the garage-to house interface.

4.2 CONTAM Modelling Analysis

Modelling results for the 42 sample houses is presented in Appendix B. Samples of the CONTAM model test results for the cold start and the hot soak tests are presented in Figure 8 and Figure 9, respectively for sample Va 04. This particular house was a three-storey end unit of a new row house located in Vancouver. The building was constructed using airtight drywall and had the mechanical room located at the garage-to-house interface. The maximum carbon monoxide and benzene concentrations in the house and in the garage are presented in Table 12.

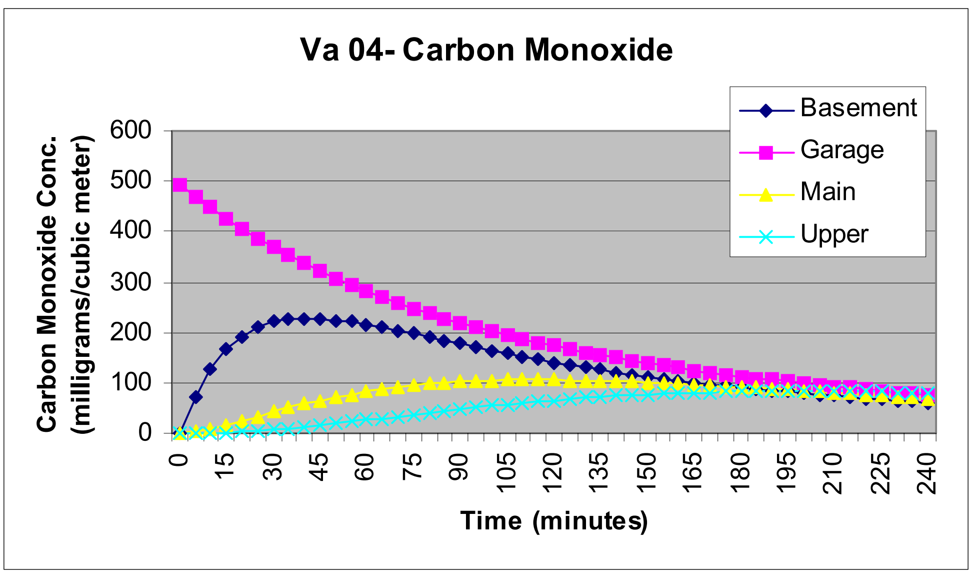

Figure 8: Cold Start Test for Va 04

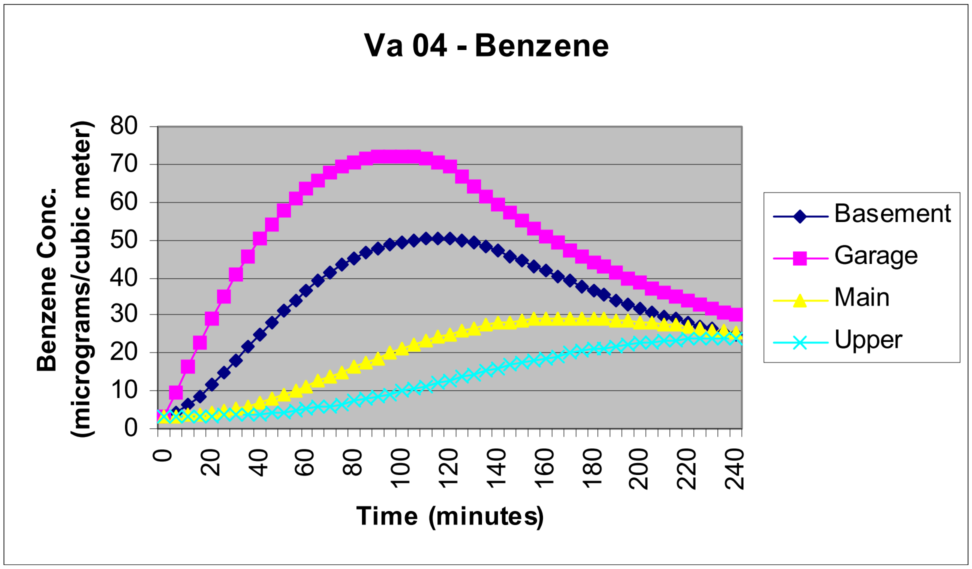

Figure 9: Hot Soak Test for Va 04

Table 12: Summary of CONTAM Modelling Results

House ID	Max. Garage CO Conc. [milligrams/cubic meter]	Max. House CO Conc. [milligrams/cubic meter]	Max. Garage Benzene Conc. [micrograms/cubic meter]	Max. House Benzene Conc. [micrograms/cubic meter]	House CO Exceeds 28.5 [milligrams/cubic meter for 1 hour][8]	Garage- to House Interface Leakage [% ELA]
Va 01	821	1	53	3	no	0%
Va 02	349	43	32	13	**yes**	**28%**
Va 03	456	24	66	9	no	3%
Va 04	448	228	72	50	**yes**	**46%**
Va 05	564	24	60	15	no	8%
Va 06	440	4	23	4	no	1%
Va 07	1,020	19	84	14	no	5%
Va 08	594	299	50	40	**yes**	**58%**
Va 09	357	1	88	3	no	5%
Va 10	436	148	50	30	**yes**	**28%**
Va 11	544	2	56	5	no	5%
Va 12	345	16	26	6	no	4%
Va 13	382	16	65	5	no	14%
Va 14	518	20	45	6	no	2%
Va 15	805	8	108	5	no	7%
Va 16	559	1	63	4	no	4%
Va 17	566	26	48	9	no	0%
Va 18	312	18	34	7	no	9%
Va 19	586	26	64	10	no	5%
Va 20	586	18	77	8	no	4%
Wi 01	394	24	33	4	no	3%
Wi 02	456	1	105	8	no	14%
Wi 03	339	25	58	10	no	24%
Wi 04	453	41	76	14	no	24%
Wi 05	805	31	67	11	no	10%
Wi 06	340	9	70	5	no	8%
Wi 07	374	10	63	6	no	9%
Sa 01	388	3	60	3	no	10%
Sa 02	418	45	86	3	no	20%
Sa 03	349	7	75	5	no	19%
Sa 04	530	33	80	12	no	22%
Sa 05	373	4	102	4	no	5%
Sa 06	379	7	81	5	no	6%
Sa 07	388	3	89	4	no	6%
Sa 08	164	3	17	4	no	1%
Sa 09	425	11	71	6	no	8%
Sa 10	208	10	52	5	no	5%
Sa 11	293	3	65	3	no	5%
Sa 12	394	3	35	4	no	15%
Sa 13	312	7	31	5	no	20%

[8] This is equivalent to 25 ppm and represents the Health Canada acceptable short-term exposure range (ASTER) for carbon monoxide.

Sa 14	440	4	95	4	no	3%
Sa 15	401	14	83	6	no	9%

4.2.1 Observation of the CONTAM Modelling

A number of items were observed as part of the modelling exercise:

- Interior concentrations of carbon monoxide and benzene were correlated with the interface leakage area. In general, higher leakage rates correspond with higher indoor concentrations of pollutants.

- Interior concentrations of carbon monoxide and benzene were correlated to house and garage airtightness. As the houses and garages became tighter, the maximum concentrations of pollutants increase, as does their residence time.

- In cases where the interface leakage represented more than 25% of the total house leakage, the concentrations of carbon monoxide and benzene tended to increase significantly indoors. This situation occurred in a number of test homes located in Vancouver, including Va 02, Va 04, Va 08, and Va 10. For these houses, indoor levels of carbon monoxide exceeded the one hour 28.5 mg/m^3 exposure limit recommended by Health Canada. This information is summarized in the last two columns of Table 7.

- None of the homes tested in Winnipeg or Saskatoon exceeded pollutant exposure limits on the basis of the current modelling.

- All of the Vancouver homes with leaky interfaces had the mechanical rooms accessed through the garage. One house was an existing single family home (Va 02), while three were new row houses (Va 04, Va 08 and Va 10).

- Maximum benzene concentration in garages is correlated to garage airtightness and inversely correlated to garage volume. In other words, small, relatively tight garages were found to have high concentrations of benzene. Using the 80 microgram per cubic meter benchmark, 10 of the 42 garages had elevated benzene concentrations.

4.2.2 Summary: Extent of Houses with Interface Leakage that Could Result in Negative Health Implications

Four of the houses modelled (Va 02, Va 04, Va 08, Va 10) exceeded recommended exposure limits for CO, while no houses exceeded exposure recommendations for benzene. Based on the current analysis, garage interfaces should be sufficiently tight to ensure that less than 25% of the house leakage occurs through the interface.

4.3 Testing and Modelling of Remediation Strategies

4.3.1 Remediation Strategy 1: Sealing of Garage-to-House Interface

The garage-to-house interface was temporarily sealed in test house Va15. The door and window trims of the garage-to-house interface were sealed using duct tape. The door threshold was found to have a significant gap, and this was filled with sealant. The House Test, Garage Test and Balanced Test were repeated with the addition of the temporary sealing. Based on these tests, it was found the interface leakage area decreased from 219 cm^2 to 116 cm^2. It should be noted that Va 15 was relatively leaky, both in terms of the house (10.9 AC/H @ 50Pa) and in terms of the garage (27.7AC/H @ 50 Pa). In addition, the interface leakage was smaller than the average at 0.4 AC/H @ 50Pa versus 0.8 AC/H @50 Pa. In terms of the modelling results, the peak concentration of benzene increased in the garage from 108 micrograms per cubic metre to 111 micrograms per cubic metre, while the peak concentration decreased in the living space from 5.3 micrograms per cubic metre to 4.4 micrograms per cubic metre.

From our observations in newer tighter houses, there are few cracks and holes to seal up with this type of remediation strategy. The primary opportunity for air sealing, using caulking and foam to seal obvious cracks and leaks, is in old leaky houses. However, in all the leakier houses in our study, we saw high dilution of contaminants due to a high house air change rate. If a leaky house is air sealed, then they should also make a good effort to seal the house/garage interface in order to avoid creating problems.

Results of the Scanada testing identified primary leakage sites of the garage-to-house interface, and include:

- Basement headers,
- Pipe penetrations from the basement into the garage,
- Forced air heating supply duct chases in common walls,
- Plumbing penetrations in walls of powder rooms or laundry rooms next to garages,
- Lowered ceilings abutting against the house/garage common wall,
- Cold air returns passing through stud space in the common walls,
- Untapped or damaged drywall joints on the garage side of common walls, and
- Pocket door in partition abutting common walls.

Air sealing of problem garage-to-house interfaces should therefore concentrate on these locations. Air sealing of the interface of the garage ceiling and a room above is particularly difficult to accomplish without removal of parts of the garage ceiling drywall.

4.3.2 Remediation Strategy 2: Installation of a Transfer Grille

A 150 mm (6 inch) circular transfer grille was installed in the wall of the garage in VA10. Initial tests were completed with the grille blocked off, then the tests repeated with the transfer grille unsealed. For the purpose of modelling, the same procedure was followed.

Initial CONTAM runs were completed with the transfer grille absent, subsequent tests were completed with the transfer grille installed. Results of the CONTAM modelling on peak carbon monoxide and benzene concentrations are summarised in Table 13 and Figure 10. The presence of the grille has a modest impact on the peak concentration of carbon monoxide and benzene in the house and garage. However, due to the high garage-to house leakage area of this particular house, carbon monoxide levels still exceed the one-hour average exposure limit of 28.5 mg/m^3.

Table 13: Impact of Transfer Grille on Pollutant Concentrations

	Transfer Grille Sealed		**Transfer Grille Un-sealed**	
	Garage	**House**	**Garage**	**House**
Carbon Monoxide [milligrams/cubic meter]	436	148	436	117
Benzene [micrograms/cubic meter]	50	30.5	37	22

It should be noted in the table above that carbon monoxide concentrations remain constant with the transfer grille sealed or unsealed, whereas benzene concentrations vary. This difference is due to the test procedure modelled. In the case of the cold start test, a fixed amount of carbon monoxide is discharged at the beginning of the test, so the peak (initial) concentration of carbon monoxide in the garage is independent of mixing or dilution. Conversely, the benzene discharge in the hot soak test occurs over a two-hour period, so the peak concentration will depend on dilution and mixing.

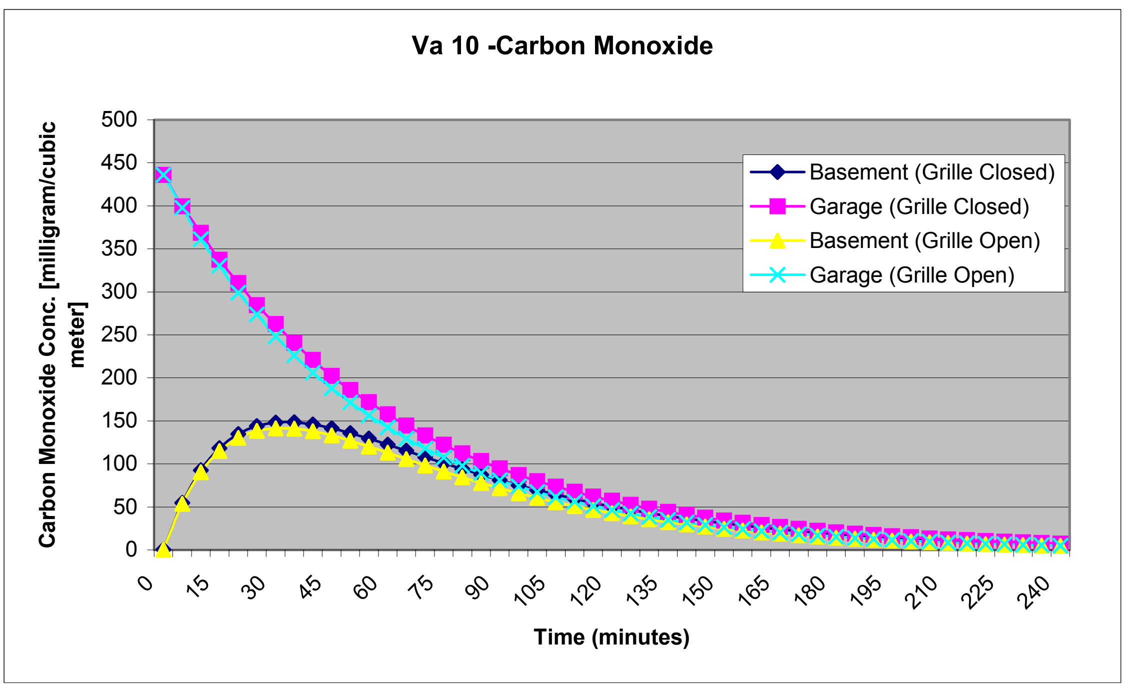

Figure 10: Impact of Transfer Grille on Carbon Monoxide Concentration in Va 10

A further set of simulations was completed to assess the impact of increasing the grille size. Figure 11 summarises the results of tripling the transfer grille located within the garage. As can be seen, while concentration of the pollutant does decrease with increased grille area, peak concentration of carbon monoxide still exceeds Health Canada acceptable short-term exposure recommendations for 1-hour duration.

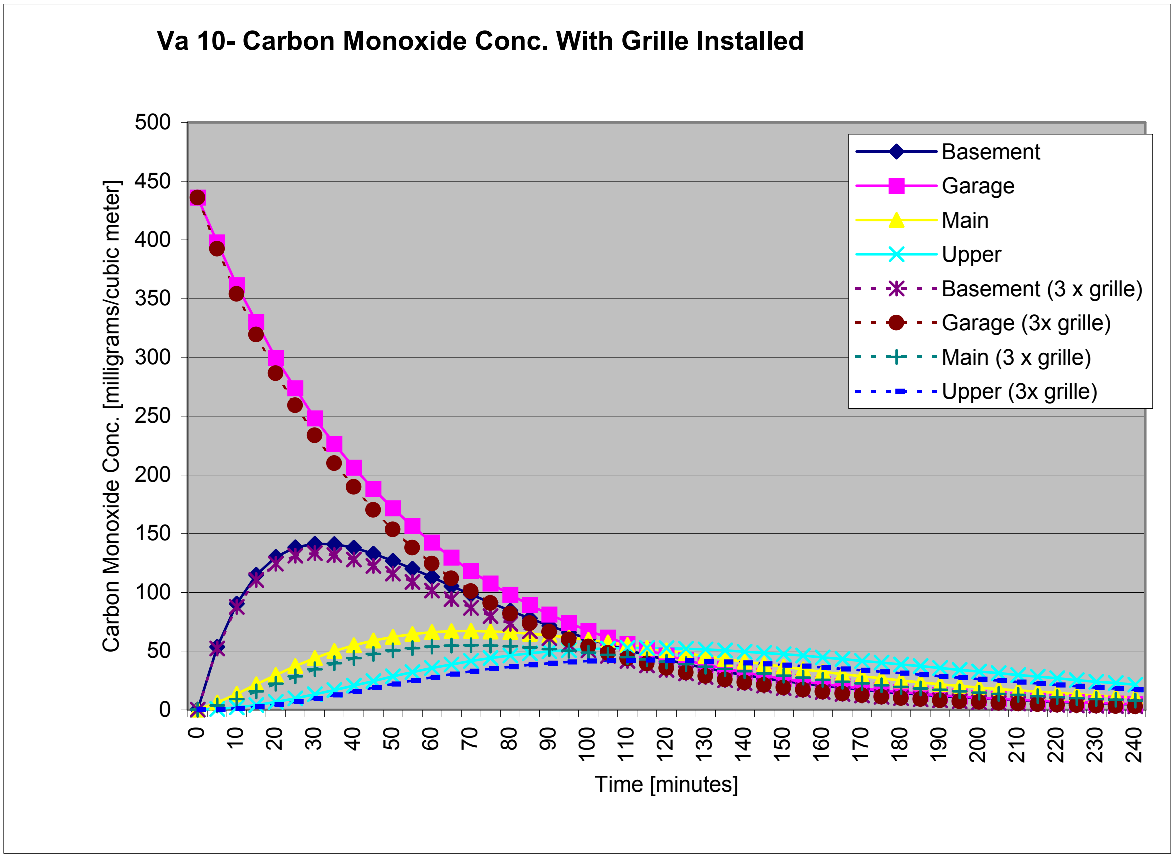

Figure 11: Impact of Transfer Grille Size on Carbon Monoxide Concentration

Based on this analysis, the primary cause of elevated pollutant levels from garages is attributable to a leaky garage-to-house interface rather than an excessively tight garage. While installation of the transfer grille does reduce pollutant levels indoors, it did not provide an adequate solution in Va 10 to mitigate the carbon monoxide exceedence. Therefore, installation of a transfer grille was not a suitable remediation strategy for this house.

4.3.3 Remedial Measure 3: Installation of Fan

The impact of a 30 L/sec fan was modelled in CONTAM based on the installation of this device in Va 03[9]. Initial CONTAM runs were completed with the exhaust fan absent, and subsequent tests were completed with the fan running. Results of the CONTAM modelling on peak carbon monoxide concentrations in the house as well as benzene concentration in the garage and house are summarised in Table 14. As can be seen, the presence of the fan has a significant impact on the peak concentration of carbon monoxide in the house, as well as on the peak concentration of benzene in the house and garage

Table 14: Impact of Exhaust Fan on Pollutant Concentrations

	Exhaust Fan not installed		Exhaust Fan installed	
	Garage	House	Garage	House
Carbon Monoxide [milligrams/cubic meter]	456	24	456	18
Benzene [micrograms/cubic meter]	66	9	54	7

4.3.4 Summary: Remediation Strategies for Reducing Contaminant Transfer Between Garages and Houses.

Three remediation strategies were tested, including sealing of the interface area, installation of a transfer grille and installation of an exhaust fan. All three strategies were found to reduce peak concentration of pollutants in both the garages and the houses where they were tested. The transfer grille was installed in a house where carbon monoxide exceeded Health Canada recommendations. Based on simulations, while peak concentrations of the pollutant were reduced as a result of installing the grille, the impact was not sufficient to eliminate the high indoor pollutant levels.

[9] An exhaust fan was installed in this garage.

5 Discussion

5.1 Relationship Between Leakage Characteristics And Indoor Pollutant Levels

Peak contaminant levels are summarised in Table 12. Based on the analysis of the 42 homes, the ratio of interior to garage peak CO ranges from 0.1% to 51%. The mean of the ratio of maximum interior carbon monoxide concentration to peak (initial) garage carbon monoxide concentration was 4.2%[10]. The average initial peak concentration of carbon monoxide was in the 42 house sample was 460 milligrams/cubic meter, while the mean of the peak indoor concentration of carbon monoxide was 16 milligrams/cubic meter[11]. These levels are well below the 1-hour exposure recommendation of 28.5 milligrams per cubic meter (25 ppm) for carbon monoxide[12]. However, for those homes where more than 25% of the house leakage occurred through the interface, the maximum concentration of interior carbon monoxide was much higher. For example, in the case of VA 08 and Va 10, the peak concentration of carbon monoxide in the living space was 50% of the initial (peak) concentration in the garage.

An analysis of the relationship between leakage characteristics and pollutant concentration was completed. This information is presented in Figure 12. Correlations were developed between indoor maximum carbon monoxide concentrations and the air leakage characteristics of

- the house,
- the garage and
- the garage-to-house interface.

It was found that interior carbon monoxide concentrations were most strongly correlated to the house to garage interface leakage. It was also found that interior carbon monoxide levels were correlated to the inverse of the house leakage area and the inverse of the inverse of the garage leakage area. This implies that:

- Reducing the ELA of the garage-to-house interface reduces the peak interior concentration of carbon monoxide;
- Increasing the ELA of the garage reduces the peak interior concentration of carbon monoxide; and
- Increasing the ELA of the house reduces the peak interior concentration of carbon monoxide

These three factors were combined to define the denominator in Figure 12.

[10] The average was 6.3% and is skewed by the four homes with high garage-to-house leakage.
[11] While the median of the peak concentration is 16 mg/m^3, the average is 30 mg/m^3, and again is skewed by the houses with elevated garage-to-house leakage.
[12] Health Canada

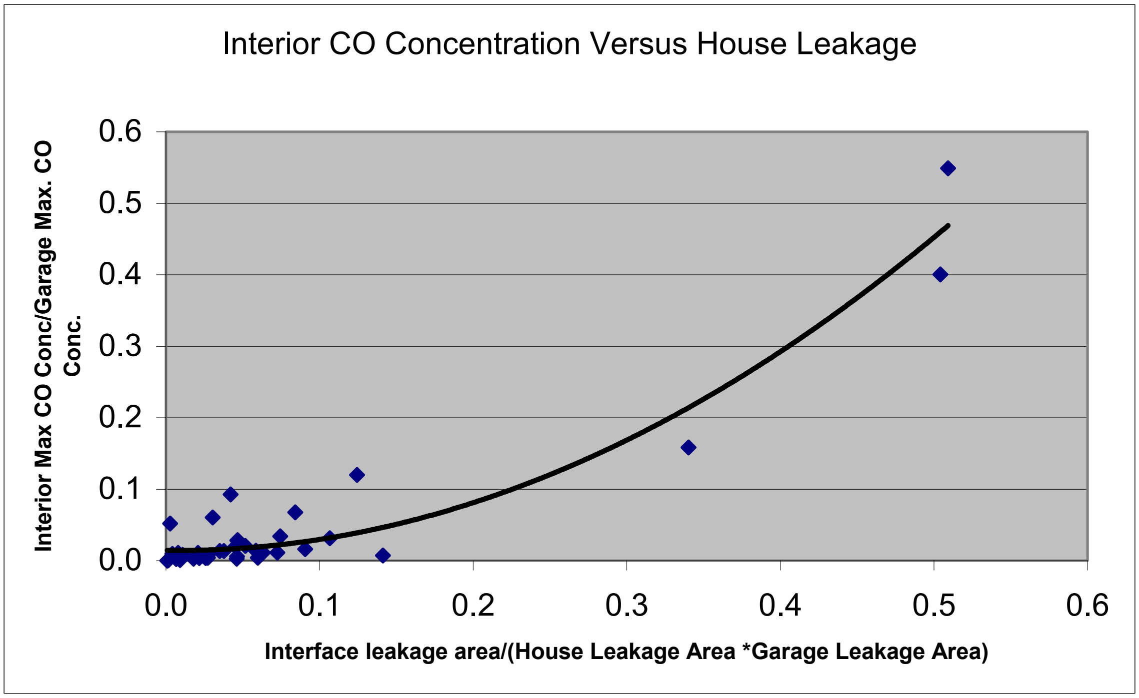

Figure 12: Carbon Monoxide Concentration in House Versus Leakage Characteristics

Another issue identified through the modelling is that in relatively tight garages, the maximum benzene concentrations reach elevated concentrations. As noted previously, the US EPA has established the health benchmark for benzene at 80 micrograms per cubic meter. Some of the tighter garages sampled in Saskatoon were found to exceed this level. Figure 13 illustrates maximum benzene concentration versus garage normalized leakage area (NLA). The NLA was used here to account for both leakage area and garage size. Based on these results, garages should have an NLA greater than approximately 2.5. Alternatively, if garages are to be constructed to these levels of airtightness, provision of an exhaust fan should be considered.

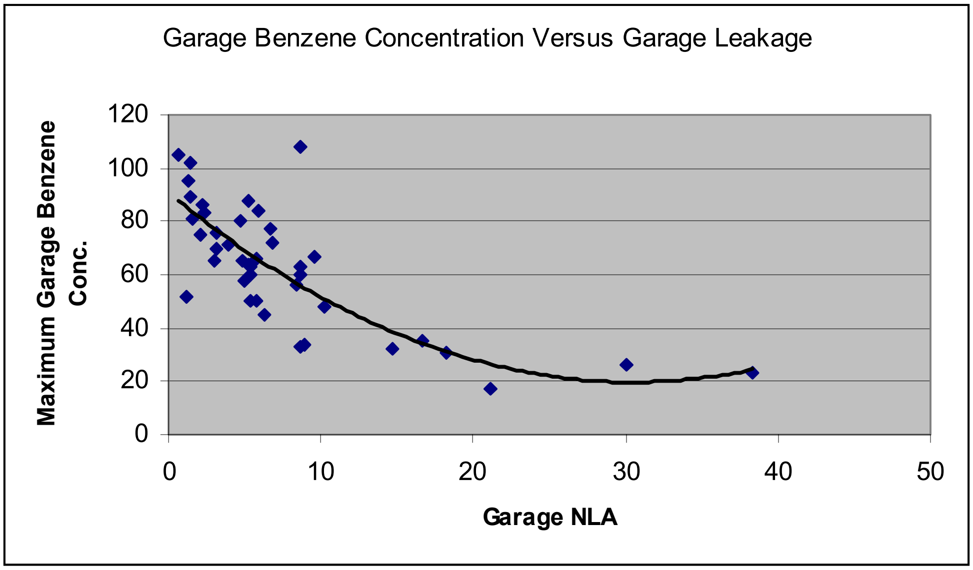

Figure 13: Maximum Benzene level in Garage versus Garage Airtightness

5.2 Characterization of the Garage to House Leakage Area

The 42 house sample results were combined with the Scanada results of 25 houses to develop a histogram of garage-to-house interface leakage. This information is summarised in Figure 14. As can be seen, 21 of the 67-house sample have a garage-to-house leakage of 5% or less. In fact, four in the sample had 0% of the leakage occurring through the garage-to-house interface. In total 60 out of 67 (90%) of houses tested have a garage-to-house interface leakage less than 25%. However, the remaining 10% have interface leakage that exceeds the threshold proposed.

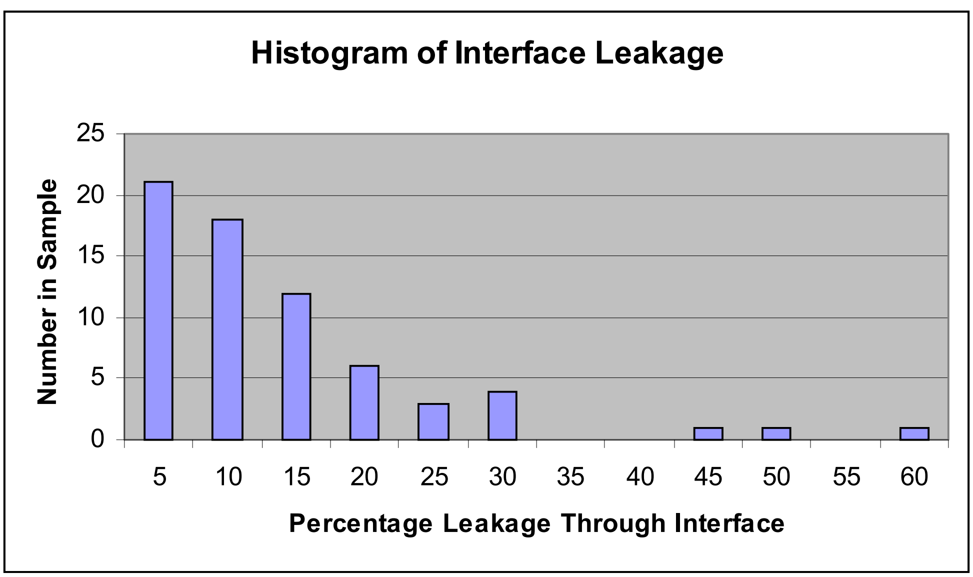

Figure 14: Interface Air Leakage Histogram

5.2.1 Impact of house size and garage configuration

Small houses with garages built in have a much higher ratio of interface area to total house envelope area and therefore it is much more important to control interface leakage in these types of buildings. For example, the average ratio for interface area to house envelope area is six percent for single-family homes and eighteen percent for townhouses. This factor is likely a significant contributor to why the townhouses show problems.

An analysis was completed of garage attachment and the portion of house leakage occurring through the garage-to-house interface. This information is summarised in Table 15. All units were able to achieve zero leakage through the garage-to-house interface. While the maximum garage-to-house leakage occurred for homes with one-sided attachment, the presence of living space over the garage does dot result in a significantly increased ELA.

Table 15: Garage Attachment and House-to-Garage leakage

Garage Attachment	Number in sample	Min. ELA [%]	Max. ELA [%]	Average ELA [%]
One Side	32	0%	50%	11%
One Side Plus Living Space Over	19	0%	58%	15%
Two Side	12	0%	24%	11%
Two Side Plus Living Space Over	4	0%	23%	11%

5.3 Thresholds for Potential Indoor Air Quality Concern

Four houses in a sample of 42 houses were found to have indoor CO concentrations in excess of health Canada one hour Acceptable Short Term Exposure Recommendations (ASTER) of 28.5 mg/m^3 (25 ppm). These four were the only houses tested with a garage-to-house interface leakage greater than 25% of the total house ELA. Therefore, it is suitable to establish a threshold of less than 25% of house leakage through the garage-to-house interface as sufficient to control pollutant transfer from attached garages into living space. While this provides an upper threshold, the current analysis does not provide adequate information to conclude that problems will not occur at lower garage-to-house leakage levels.

5.4 Parametric Analysis of CONTAM Results

This section presents results of CONTAM modelling results for a single-family house under a range of conditions to assess garage and house pollutant levels. A house was originally calibrated with tracer gas tests and subsequently modelled using CONTAM to investigate the impact of alternative measures to reduce pollutant transfer[13]. Using the cold start and hot soak tests, a range of parametric runs were completed to assess the impact of:

1. Increasing the pollutant concentration by a factor of three
2. Reducing the garage-to-house interface leakage by a factor of two
3. Reducing the outdoor temperature from 10 degrees Celsius to minus thirty degrees Celsius
4. Installing a 25 litre per second fan that runs for 30 minutes
5. Installing a 100 litre per second fan that runs for 30 minutes

The results of these strategies on garage pollutant concentration and house pollutant concentration are shown in Figure 15 and Figure 16, respectively.

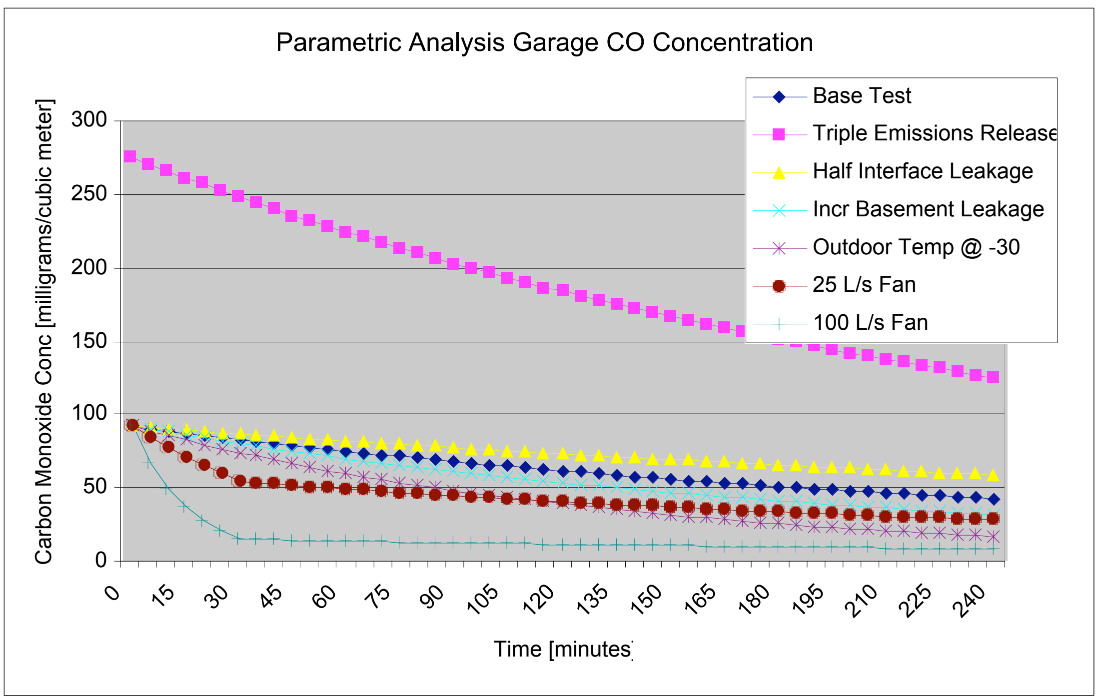

Figure 15: Parametric Results of Garage CO concentration

[13] Personal communication, Don Fugler, CMHC, 2002

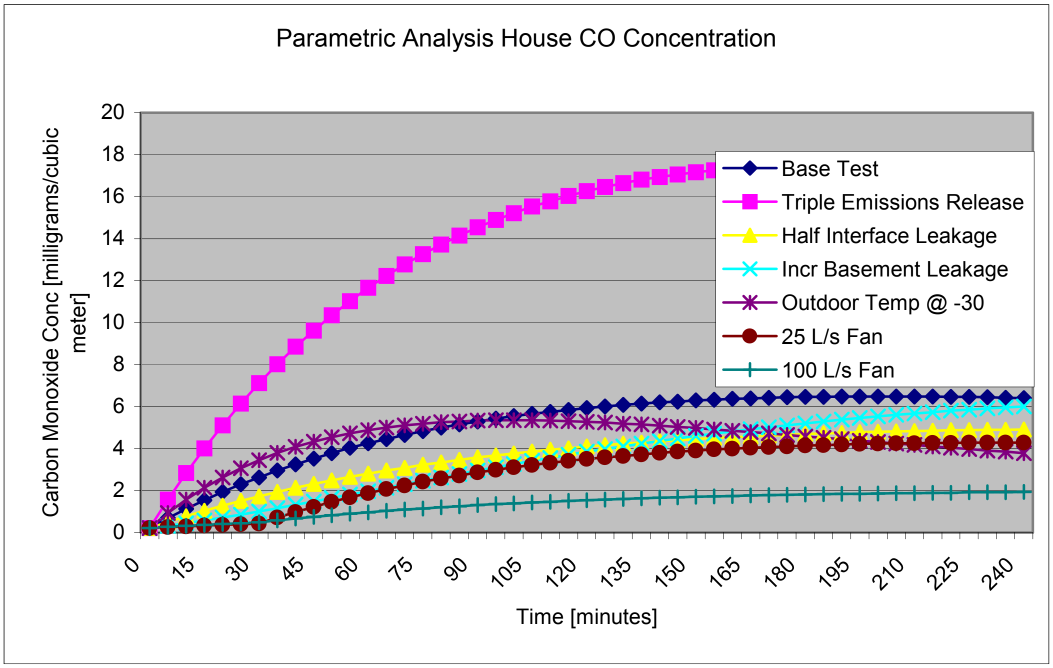

Figure 16: Parametric Results of House CO concentration

Observations of these runs are that:

- Increasing the initial pollutant concentration in the garage has a significant impact on the peak concentration of pollutant in the house.
- Reducing the garage-to-house interface leakage increases garage pollutant levels and reduces house pollutant level.
- Increasing the basement leakage area while maintaining the house total leakage reduces garage concentrations and concentration of the main floor in the house.
- Reducing the outdoor temperature from 10 degrees Celsius to minus 30 degrees Celsius increases stack effect which increases pollutant dispersal.
- Installation of the 25 and 100 litre per second fan reduces pollutant levels significantly in both the garage and the house.

5.5 Suitability of Remedial Measures

Based on the current analysis, the primary cause of pollutant transfer is poor air leakage control of the garage-to-house interface. Therefore improving the airtightness of that interface appears to be the preferred approach.

5.5.1 New Construction

In new homes, this may be accomplished through eliminating penetrations of the garage-to house interface. In particular, placing the mechanical room at this interface should be avoided. Eliminating the man door between the garage and house may also be considered. Minimising electrical and mechanical penetrations should also be considered.

5.5.2 Use of Airtight Drywall in New Construction

Airtight Drywall (ADA) was used in a number of the new town house buildings tested in Vancouver, primarily to ensure continuity of the air barrier. The ADA strategy included:

- ADA gaskets at bottom plates. Bottom plates were not sealed to concrete inside garage, but are sealed to concrete floor on inside of house/garage interface walls, as part of regular ADA application on house exterior wall.
- ADA gaskets at door openings.
- Mechanical and house door frames sealed to rough openings and sills to floor
- ADA gasketed electrical boxes

This strategy resulted in reduced interface leakage than other similar townhouse projects. As shown in Table 16, the average interface leakage ELA of the two units with ADA in the garages are 48 cm^2 (6% of house leakage) compared to 277 cm^2 (30% of house leakage) for townhouses without ADA in garages. While VA18 shows that conventional construction techniques can be as effective as ADA, in this small sample, the ADA house interfaces appear to be more consistently tight. The two townhouses with ADA in garages are similar to the other five, all with mechanical rooms between garages and living areas accessed from the garages, and all with similar weather-stripping at doors between garages and living areas.

Table 16: Impact of ADA In Controlling Garage-to-House Leakage

	Interface ELA (cm^2)	% of House Leakage
Townhouses without ADA in Garages		
VA 04	254	46%
VA08	588	58%
VA10	222	28%
VA13	186	14%
VA18	135	5%
Average	*277*	*30*
Townhouses with ADA in Garage		
VA19	36	4%
VA20	59	7%
Average	*48*	*6*

5.5.3 Remedial Construction

For existing homes, homeowners may air seal the interface, including weather stripping of all doors, electrical penetrations and partitions. Living spaces over attached garages are particularly difficult to seal in the case of existing dwellings. Air may enter stud walls and pass though the wall top plate into the joist space from where it can get into living space above the garage. Leakage paths may include penetrations through the ceiling as well as penetrations through walls. While the penetrations through ceilings may be relatively easy to locate and seal, penetrations through walls may be more difficult to treat. To be effective, air sealing would require that ceiling drywall be removed around the perimeter of the garage and all joints in the wood framing be sealed with foam or sealant. For this situation, installing an exhaust fan that runs for 30 minutes is likely a more cost effective solution. Fans providing 25 L/s to 100 L/s capacity are acceptable. The fan could be controlled on a timer and interlocked with garage lights.

5.5.4 Home-owner Diagnosis of Potential Problems

Garage-to-house interface leakage are not easily characterized without specialized equipment, and using a fan door test to establish whether a problem exists is costly. However, simple options do exist for homeowners to identify if a potential problem exists, including:

- Carbon monoxide alarm goes off frequently, particularly when cars started or idling in the garage
- Car exhaust fumes are detectable in the house (smell, headaches etc), and
- Cold drafts are felt adjacent to the garage-to-house interface
- Cold floors in living space over garages.

6 Conclusions

This section presents conclusions of the air quality impacts of attached garages.

6.1 Conclusions

1. Based on the airtightness testing completed on 42 homes with attached garages, it was found that on average, that interface leakage accounts for approximately 10% to 13% of the total house leakage area. These results are consistent with previous testing (Scanada, 1997).

2. If more than 25% of the house air leakage occurs through the garage, our simulations show that garage-based emissions will cause significant house indoor air quality problems. In total four of the 42 houses tested had interfaces where more than 25% of the house leakage occurred through the interface. Three of these houses were new row houses with the mechanical room located in the garage.

3. The same four houses that were found to have loose garage-to-house interfaces were found to exceed recommended exposure limits for carbon monoxide on the basis of CONTAM simulations. None of the houses modelled were found to exceed benzene exposure limits.

4. Three remediation strategies were tested. All three strategies were found to reduce peak concentration of pollutants in both the garages and the houses where they were tested.
   - Installation of a transfer grille did reduce peak pollutant concentrations in the house, however, carbon monoxide levels still exceeded guidelines within the house.
   - Air leakage sealing of the garage-to-house interface results in reduced contaminant transfer, and is the preferred approach for new homes. For the case where leaks are accessible in a retrofit situation, air sealing is also achievable.
   - When leaks are not accessible, installing an exhaust fan ranging in size from 25 L/s to 100 L/S and running it for 30 minutes helps to reduce the transfer from the garage to the house of car start-up contaminants.

5. Mechanical rooms with access through the garage be discouraged due to high contaminant transfer potential in these dwellings.

7 References

Canadian General Standards Board, CGSB 149.10-M86 Determination Of The Airtightness Of Building Envelopes By The Fan Depressurization Method CGSB, 1986.

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National Institute of Standards and Technology, CONTAMW 1.0 Users Manual, 2000

Scanada Consultants Limited, Air Infiltration From Attached Garages In Canada, CMHC, Ottawa, Ont., Dec. 1997