# TRANSPORT OF CONTAMINATED GAS AND DUST IN HIGH-RISE APARTMENT BUILDINGS

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## DISCLAIMER



NOTE: LE RÉSUMÉ EN FRANÇAIS SUIT IMMÉDIATEMENT LE RÉSUMÉ EN ANGLAIS.

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## ABSTRACT

Jacques Whitford Environment Limited (JWEL) and Morrison Hershfield Limited (MH) have completed a research project investigating the level of risk associated with soil gases and dust in high-rise apartment buildings. The research was conducted in response to a request for proposals issued by the Canada Mortgage Housing Corporation (CMHC). The study investigated the hypothesis that the risk associated with gas and dust from contaminated lands can be reduced for residents of high-rise apartment buildings compared to residents of single-unit or low-rise residential structures. The study was conducted using a literature search to examine the risk associated with fugitive dust in high-rise apartment buildings, and tracer gases to examine transfer paths of gaseous phase contaminants and the effects of ventilation systems.

## EXECUTIVE SUMMARY

Jacques Whitford Environment Limited (JWEL) and Morrison Hershfield Limited (MH) undertook a research project to investigate the level of risk associated with contaminated soil gases and dust in high-rise apartment buildings. The research was conducted in response to a request for proposals issued by the Canada Mortgage Housing Corporation (CMHC). The study investigated the hypothesis that a high-rise apartment building with an underground parking garage can create an adequate concentration-reducing buffer between entry points for gaseous or dust contaminants and living spaces. If this hypothesis were true, high-rise apartment buildings subject to site specific risk assessment would be able to tolerate higher levels of soil contaminants than low-rise buildings on the site.

Three main tasks were undertaken to fulfill the objectives of the research project:

- a literature search examining the risk associated with fugitive dust in high-rise apartment buildings;
- an evaluation of transfer paths of gaseous phase contaminants using perfluorocarbon tracer gas; and
- an evaluation of the effect of ventilation systems on the transfer paths of gaseous phase contaminants using sulfur hexafluoride ($SF_6$) tracer gas.

Based on the literature search conducted, it was concluded that the risk to high-rise apartment dwellers from contaminated dust is less than the risk to dwellers in single-unit homes. Emissions of dust can be reduced or eliminated at the contaminant source, and the number of exposure pathways are reduced by the building envelope and the limited on-site outdoor activities available at a high-rise building area.

Tracer gases can be transported through the high-rise apartment buildings by means of direct or indirect pathways. Indirect pathways pass through the parking garage area and the concentrations of tracer gases are buffered by dilution in this area. Direct pathways do not travel through the general garage space. Concentrations of tracer gases in building living spaces were found to be highest due to direct transport pathways.

The study has determined that gas transfer pathways are present in the high-rise buildings researched and that these pathways are not just stack-induced, seasonal phenomena. Generally, it was found that the dominant direct pathway for gas transfer was between the elevator sump pit and the upper floor living space. Results were compared to the gas concentrations that would exist if the tracer gas were equally mixed throughout the building. In upper floors, tracer gas concentrations as high as three times the fully mixed model were found during winter testing when stack forces were present. However, these concentrations were still 3 to 5 orders of magnitude less than the concentration at the point of entry into

the garage. During summer testing, normalized tracer gas concentrations were found to be only marginally higher than the fully mixed scenario.

Building ventilation can affect the concentrations of tracer gas detected in the living spaces. The magnitude of the change caused by ventilation depends on the effectiveness and extent of the ventilation system.

To manage the risk associated with gas transfer, gas pathways into and through the building should be restricted. The effectiveness of this could be established by testing improved building construction and operation procedures.

The research has shown that significant gas transfer can occur between potential entry points for contaminated soil gases and building living space. However, the findings support the conclusion that risks from gas and dust transport in high-rise apartment buildings can be managed and identifies areas to focus on for site-specific risk management.

**RÉSUMÉ**

Les firmes Jacques Whitford Environment Limited (JWEL) et Morrison Hershfield Limited (MH) ont étudié les risques associés aux poussières et aux gaz souterrains contaminés présents dans les tours d'habitation. Faisant suite à un appel de propositions lancé par la Société canadienne d'hypothèques et de logement (SCHL), cette étude a examiné l'hypothèse selon laquelle les garages de stationnement souterrains de certaines tours d'habitation peuvent contribuer à réduire la concentration de gaz et de poussières contaminés entre leur point d'infiltration et les aires habitables. Si cette hypothèse s'avérait juste, les tours d'habitation soumises à une évaluation du risque adaptée au site pourraient tolérer de plus fortes concentrations de contamination du sol *in situ* que les bâtiments de faible hauteur.

Pour atteindre les objectifs fixés, le projet de recherche a été divisé en trois tâches principales :

- une recherche documentaire examinant le risque associé aux poussières diffuses dans les tours d'habitation;
- une évaluation des voies de transport des contaminants en phase gazeuse réalisée au moyen d'un traceur d'hydrocarbure perfluoré;
- une évaluation de l'effet des installations de ventilation sur les voies de transport des contaminants en phase gazeuse à l'aide d'un traceur d'hexafluorure de soufre ($SF_6$).

La recherche documentaire a permis de conclure que le risque que représente la poussière contaminée pour les occupants des tours d'habitation est moins grand que pour les occupants de maisons individuelles. Les émissions de poussière peuvent être réduites, voire éliminées, à la source de contamination et le nombre de voies d'exposition est réduit par l'enveloppe du bâtiment et par la quantité limitée d'activités extérieures pouvant être effectuées sur place.

Dans une tour d'habitation, les gaz traceurs peuvent se déplacer en empruntant des voies de transport directes ou indirectes. Les voies indirectes traversent le garage de stationnement et les concentrations de gaz traceur sont diluées dans ce secteur. Les voies directes ne passent pas par le

garage de stationnement. Les concentrations de gaz traceurs dans les aires habitables des bâtiments ont été les plus élevées lorsque les gaz empruntaient des voies de transport directes. L'étude a déterminé que les immeubles à l'étude présentent des voies de transport de gaz et que ces voies ne sont pas seulement créées par l'effet de tirage, un phénomène saisonnier. En général, on s'est aperçu que la voie dominante de transport direct des gaz se situait entre le puisard d'ascenseur et les aires habitables supérieures. Les résultats ont été comparés aux concentrations de gaz qu'on aurait si le gaz traceur était uniformément mélangé dans tout le bâtiment. Aux étages supérieurs, des concentrations de gaz traceur jusqu'à trois fois plus élevées que le modèle à mélange complet ont été observées lors des essais menés en hiver, en présence d'effets de tirage. Cependant, ces concentrations étaient tout de même inférieures, par un ordre de grandeur de 3 à 5, à la concentration enregistrée au point d'infiltration dans le garage. Lors des essais menés en été, les concentrations de gaz traceur normalisées se sont avérées tout juste supérieures à celles du scénario à gaz complètement mélangés.

La ventilation dans un bâtiment peut modifier les concentrations de gaz traceur détectées dans les aires habitables. L'ampleur des changements causés par la ventilation dépend de l'efficacité et de l'importance des installations de ventilation.

Pour limiter les risques associés au transport de gaz, les voies de transport vers le bâtiment et à l'intérieur même du bâtiment doivent être restreintes. L'efficacité de cette méthode pourrait être établie en mettant à l'essai des procédés de construction et des modes d'exploitation améliorés.

La recherche a montré qu'un important transport de gaz peut survenir entre les points d'infiltration potentiels des gaz souterrains contaminés et les aires habitables d'un bâtiment. Néanmoins, les résultats de l'étude portent à conclure que les risques inhérents au transport de gaz et de poussières dans les tours d'habitation peuvent être limités et font ressortir des points à surveiller quant à la gestion du risque adaptée au site.

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## 1.0 INTRODUCTION

Jacques Whitford Environment Limited (JWEL) and Morrison Hershfield Limited (MH) undertook a research project to investigate risks associated with contaminated soil gases and dust in high-rise apartment buildings. The research was conducted in response to a request for proposals issued by the Canada Mortgage Housing Corporation (CMHC). The study investigated the hypothesis that a high-rise apartment building structure with an underground parking garage can create an adequate buffer between entry points for contaminated soil gases or dust and living spaces. If this hypothesis were true, high-rise apartment buildings subject to site specific risk assessment would be able to tolerate higher levels of soil contaminants than low-rise buildings on the site.

## 2.0 OBJECTIVES

The objectives of this study are to research the transfer of contaminated soil gases and dust into living spaces in high-rise residences, and to establish from this research whether a high-rise building structure with an underground parking garage is an effective barrier to these pollutants from contaminated lands.

The major points investigated and discussed by the research study are as follows:

- the risk associated with fugitive dust in high-rise apartment buildings;
- the dominant building entry points for contaminated gases or liquids which result in the highest level of contaminant gases in the living space of the buildings;
- the relationship between the concentration of gases at entry points and the concentration of the gases in the living spaces;
- the effects of building suite or parking garage ventilation on the transfer of gases into high-rise living spaces;
- the significance of the study to existing provincial and federal soil and groundwater quality guidelines which do not distinguish between low-rise and high-rise residential buildings; and
- the significance of the study to risk management programs for contaminated lands.

# 3.0 BACKGROUND

## 3.1 Current Regulations and Policy

Federal, and in some cases Provincial, soil quality criteria are based on land use which typically groups all types of residential land use together. Maximum allowable concentrations of contaminants in soil and groundwater are derived by regulators based on specific risk scenarios which relate to the most probable mode of transport and fate of the contaminants. The specific risk scenarios from which these criteria are derived include:

- inhalation of gas or dust;
- absorption through skin contact;
- eye irritants;
- ingestion of the contaminant; and
- aesthetics (i.e. discolouration, odour).

External contaminants can enter a building in the solid phase (in the form of dust or carried by dust), in the liquid phase (when contaminated groundwater enters a sump pit), in the gaseous phase (as a result of soil gas or vapour from liquid contaminants) or it can be tracked-in by people entering the building. Once inside the building, the contaminants are distributed to living spaces primarily in the gas phase; however, the movement of dust is also possible. In typical situations, liquid contaminants from outside the building are not transferred to individual living spaces in the liquid form. It should be noted that there are numerous variables which affect the mode of transport towards, into, and throughout a high-rise building.

The hypothesis investigated in this project is that contaminant soil gases and dust present a significantly reduced risk to residents in high-rise apartment buildings as compared to residents of low-rise residential buildings (i.e. single family dwellings). If this hypothesis were to be substantiated, this study could provide a basis for regulators to reconsider soil quality criteria related to high-rise residential properties. This in turn could provide justification for preparing risk management programs in lieu of meeting provincial soil and groundwater quality criteria for high-rise apartment buildings constructed on or adjacent to contaminated lands.

## 3.2 Entry of Gases from Soils or Groundwater

In the research conducted, it was assumed that volatile liquids and/or soil gases can enter the building envelope at locations such as sump pits, floor drains and pipe entrances through outside-wall slabs. Before coming into contact with a subject building, a soil or groundwater contaminant must first be transported through subsurface media. The amount of contamination that reaches the building is dependent upon factors such as:

- the groundwater depth, gradient, and flow direction;
- the solubility, density, and other chemical characteristics of the contaminant;
- the soil type encountered between the source and the building; and
- the presence of high permeability conduits such as service trenches.

Once a liquid or gaseous contaminant has reached the outside of the subject building, the probability of it entering the building envelope is dependent on many factors, including:

- the integrity of the building floor and wall slabs;
- the presence of a protective membrane around the building foundation;
- the construction of sump pits (concrete versus natural soil or bedrock); and
- the pressure differential (i.e. positive or negative pressure) between the building basement and contaminated soil gases in the subsurface media outside the building.

The risk associated with the presence of contaminants inside the building envelope is associated with:

- the toxicity and physical characteristics of the contaminant;
- the concentration and volatility of the contaminant; and
- building-related factors such as entry points and building ventilation.

## 3.3 Subject Buildings

Three buildings were selected for the investigation of gaseous phase contaminants in high-rise apartment buildings. Building details are provided in **Table 3.3.1**.

| Table 3.3.1: Building Information | | | |
|---|---|---|---|
| | **Building A** | **Building B** | **Building C** |
| Year of Construction | 1969 | 1975/76 | 1972 |
| Number of Garage Levels | 1 | 2 | 2 |
| Number of Above-Ground Storeys | 15 | 20 | 18 |
| Suite Exhaust Systems* | Individual | Central | Individual |
| Garage Ventilation System | CO Control | Timer | CO Control |

* all buildings had central make-up air supply systems discharging to corridors

Building A had a shared garage with an adjoining building. The capacity of the joint ventilation system was 52,350 L/s. This system was activated when the carbon monoxide levels in the garage reached 100 ppm. The garage doors for this building were normally left open. This provided sufficient ventilation so that the garage exhaust ventilation was normally not active. The make-up air system for Building A was not shared with the adjoining building. Building A utilized a 2,600 L/s make-up air system located at ground level, and a 1,640 L/s system located on the roof of the building for the seventh floor. Both make-up air systems provided air to the corridors. The system located on the roof provided make-up air to the top half of the building (i.e. above the sixth floor), while the ground floor system provided make-up air to the remaining lower floors.

The garage ventilation system in Building B had a capacity of 19,000 L/s. It was reported to operate for 9 hours per day to correspond to peak activity in the garage. The make-up air system had a capacity of 6,100 L/s and provided make-up air to the corridors. Building B also had a central exhaust system servicing each suite which had a capacity of 3,851 L/s.

Building C had a 13,200 L/s garage exhaust ventilation system. The system was activated when the carbon monoxide level reached 50 ppm and shut off when this level dropped below 30 ppm. This system was reported to operate on average for 2-3 hours in the morning and late afternoon, corresponding to periods of peak activity. The make-up air system provided make-up air to the corridors.

## 4.0 METHODOLOGY

Three main tasks were undertaken to fulfill the objectives of the research project:

- a literature search examining the risk associated with fugitive dust in high-rise apartment buildings;

- an evaluation of transfer paths of gaseous phase contaminants; and
- an evaluation of the effect of ventilation systems on the transfer paths of gaseous phase contaminants.

Details concerning the methodology used to complete these tasks are given in the following subsections.

## 4.1 Dust Investigation

Previously conducted research projects were reviewed for information pertaining to the migration of dust into and throughout high-rise apartment buildings. The relationship between contamination sources and the toxicity of their dusts was also examined. A risk assessment approach was taken to evaluate the risk to residents in high-rise apartment buildings from dust migration from contaminant sources.

Using the risk assessment approach, for a risk to be present in an environment there must be a hazard, an exposure pathway and a receptor of the risk. If one of these aspects of risk is not present in a situation, there is no risk.

In this situation, a hazard is assumed to exist in the form of dust originating from the contaminated soil.

The receptors are high-rise apartment building residents. Receptors in a high-rise apartment building setting can be children or adults of all ages and economic or cultural backgrounds. No generalities can be made with respect to the amount of time that a resident is in the indoor high-rise apartment environment.

A hazard is assumed to be present in all cases and the receptor is constant; therefore, the exposure pathway must be examined to determine if a risk is present.

There are two main aspects of exposure to be considered:

- the emission of the contaminant from the source; and
- the pathways by which the contaminant can travel from the source to the receptor.

<u>Emission from the Hazard</u>
Contaminated dust can be emitted from the source when humans walk or play on the soil or when surface dust is disturbed by winds or vehicles.

Pathway to the Receptor

A high-rise apartment building situation limits the number of paths available for dust transport between a contaminated soil source and a human receptor. Dust exposure to humans can occur through ingestion, inhalation, or dermal contact. The risk associated with dermal contact is not discussed in this report because it rarely applies to high-rise buildings and because dermal contact has a very contaminant-specific nature.

In a high-rise building situation, it is assumed that exposure of inhabitants to dust while outside the building is limited. This is unlike the situation in residential single-unit homes in which inhabitants play, work, and relax outdoors as well as indoors. Ingestion exposure from personal gardens at the apartment site is also considered to be negligible. The pathways considered to be of significance to the given scenario are inhalation and ingestion of soil particles and dusts which can enter a building envelope through air passages or can be brought in on shoes.

Information relevant to the emission and transport of dust in high-rise apartment buildings were identified through a literature search. The following sources were consulted:

- JWEL offices across Canada;
- Ontario Ministry of the Environment and Energy (MOEE), Environment Canada, and Health Canada officials;
- Interim Waste Authority reading room;
- Compendex Engineering Information CD Rom abstracts;
- Risk Assessment documents produced by the United States Environmental Protection Agency (EPA); and
- Environment Abstracts Annual 1990 - 1994 (including available technical papers).

## 4.2 Evaluating Transfer Pathways of Gaseous Phase Contaminants

### 4.2.1 Overview of Methodology

Tracer gases were used to determine the dominant pathways which could be taken by soil gases into the living spaces of a building. For the purposes of this study, the transfer pathways were defined to be either direct or indirect. A pathway was considered to be direct if it did not pass through the parking garage area. On the other hand, indirect pathways were those which passed though the parking garage before entering the building.

The principle behind tracer gas methodology is to monitor the movement of a uniquely identifiable tracer gas from its emission source to various locations within the building. Three unique Perfluorocarbon Tracer (PFT) gases were used in this study which allowed for the determination of pathways from three different emission sources. Passive samplers were used to measure the PFT concentrations.

Testing was conducted under summer and winter conditions to assess the effect of seasonal changes on the gas transfer pathways and the effect of stack forces. The schedule for all testing is presented in **Appendix 1**.

### 4.2.2 Location of Emission Sources

For each building, possible entry points for soil gases were investigated. At each established entry point, a unique PFT source was installed. The entry points examined in this study are presented in **Table 4.2.1**.

**Table 4.2.1 Potential Entry Points for Soil Gases (Emission Source Locations)**

| Building | Potential Entry Points | | |
|---|---|---|---|
| A | Elevator Sump Pit | Floor drain | Pipe Entrance through exterior wall |
| B | Elevator Sump Pit | Floor drain | Pipe Entrance through exterior wall |
| C | Elevator Sump Pit | Secondary Sump Pit | Pipe Entrance through garage ceiling slab |

As can be seen in **Table 4.2**, source locations included elevator sump pits, floor drains, and pipe entrances through outside walls. The potential entry points considered were those through which liquid or gaseous phase contaminants could enter the below-grade portion of the building envelope.

In Building C, one emission source was located at a pipe entrance through the garage ceiling slab. This entry point is a secondary source location because contaminated soil gases from other entry points would have already been diluted in the garage buffer by the time they reach this point. The concentration of the PFT emitted by the source at this location would be artificially higher on the floor above than those normally found for an indirect pathway because of the unsealed pipe opening in the ceiling slab.

### 4.2.3 Sampling Locations

Passive Carbon Adsorption Tube (CAT) samplers (see **section 4.2.4**) were installed at various locations throughout the buildings to measure PFT gas concentrations at emission sources and in the living spaces. The living spaces on three floor were monitored: samplers were placed on the top, middle, and ground floors of each building. For each floor, samplers were placed in two apartments and in the corridor. Office or laundry areas had to be used in some cases instead of apartments for the ground floor monitoring. Samplers were also placed at selected garage locations and at all source locations to measure the dilution of the PFT between the source or buffer space locations and the living space. **Table A2-1** provided in **Appendix 2** lists the monitoring points in each building.

### 4.2.4 PFT Emission Sources and Capillary Absorbent Tube (CAT) Passive Samplers

The perfluorocarbons used in this study were liquids at room temperature and atmospheric pressure. When these perfluorocarbon liquids are placed in a permeation device (the emission source), a constant rate of PFT vapour is emitted. This vapour can then be carried by convective air currents away from the source into other parts of the building. The emission sources consisted of a number of individual PFT tubes. PFT gases were typically emitted from the emission sources at a rate of $1x10^{-5}$ - $1x10^{-6}$ L/hour. The emission rate for each source was calculated based on the temperature measured during source installation. Three sources, each emitting a unique perfluorocarbon at a known rate, were installed in each building.

Capillary Absorbent Tubes (CATs) were installed for gas collection at desired monitoring points. The CATs sample tracer gas by a process of passive diffusion and adsorption onto charcoal. Subsequent thermal desorption and gas chromatographic analyses result in measurements of the tracer concentration.

CATs and PFTs were obtained from Brookhaven National Laboratory (BNL) in Upton, New York. Analysis of CATs was also conducted at BNL. Previous testing has shown that, if conducted properly, results obtained from the BNL-tracer system are in good agreement with results obtained from conventional $SF_6$ methods[1]. It should be noted that the emission rate is relatively sensitive to the ambient temperature in the source area. For example, a 3°C error in temperature can result in a 13% to 16% error in the emission rate. However, this potential error does not hinder the evaluation of transfer paths.

CAT samplers located beside the PFT sources or other areas of high concentration were not exposed to the source on a continuous basis in order to avoid saturating the CAT samplers. During the summer round of testing, flow restrictors were used on CAT samplers located in areas of high PFT concentrations to further reduce PFT loading. The total exposure time (including the use of flow restriction devices) was recorded for each CAT installed.

One CAT sampler was held as a travel blank for each testing round for both winter and summer. This CAT tube was exposed to the same travel conditions as the other samplers but was never opened for absorption in any of the buildings. The purpose of this CAT sampler was to evaluate the level of contamination, if any, experienced by the CAT tubes, outside of the absorption period.

Following an absorption period of approximately three weeks, all monitoring samplers and the travel blank were collected and submitted to BNL for analysis.

### 4.2.5 Normalized Concentrations and Dilution Ratios

To facilitate interpretation of the raw data, concentrations detected through analysis were normalized relative to the tracer gas concentration that would be found if the tracer gas were injected and fully mixed directly into the living spaces. The formula used to normalize the data is as follows:

$$\textbf{Normalized Concentration} = \frac{\textbf{Source Rate}}{\textbf{Removal Rate}}$$

where the source rate is calculated using temperature dependent source emission rates provided by BNL, and the removal rate is a function of the calculated volume of building living space. The building air change rate was based on one air change per hour.

Generally, a normalized concentration of greater than one displays a strong transfer path. Normalized concentrations from winter and summer testing were compared to evaluate seasonal differences in gas transfer pathways.

Dilution ratios were also used to evaluate the PFT gas concentration data. The *dilution ratio* is defined as the concentration of the PFT gas measured at the sample location divided by the concentration measured at the emission source. A dilution ratio of one indicates that there is a strong pathway between the emission source and the living space being measured.

## 4.3 Evaluation of the Effect of Ventilation Systems

Constant source rate testing using sulphur hexafluoride ($SF_6$) tracer gas was conducted to determine the effects of the ventilation systems on the transfer of contaminated soil gases from a dominant entry point to the living spaces in the buildings. Testing was conducted under summer and winter conditions with building ventilation and air make-up systems in both the deactivated and normally-operating positions. In the deactivated position, the corridor make-up air system and the garage exhaust system were turned off in all buildings. Unlike Buildings A and C, Building B has a control suite exhaust system. This system was also turned off for testing in the deactivated position. In the normally-operating position, it should not be inferred that all ventilation systems were active throughout the test period because garage ventilation systems are triggered by either a timer (Building B) or a CO monitor (Buildings A and C) (see **section 3.3**).

A compressed gas cylinder was used to inject the $SF_6$ gas into the sump pit at a constant source rate of 0.0078 L/s (1 standard cubic foot per hour). In the ventilation-off position, gas was injected into the building for an approximate sixteen hour period (over-night). In the normally-operating scenario, sampling was conducted at least four hours after ventilation systems were reactivated. The minimum four hour period before the second sampling event was considered to be a sufficient period for the concentration of $SF_6$ to restabilize at the new airflow pattern applicable to the ventilation situation. This assumption was verified by repeat sampling. At two sampling locations, Vacutainer samples were collected at both the beginning and end of the testing round to confirm that concentrations of $SF_6$ in the building air had reached equilibrium.

Ambient air samples were collected throughout the buildings while $SF_6$ tracer gas was being injected into the elevator sump pit. Air samples were collected using a syringe to collect ambient air and inject it into a Vacutainer. Syringes were flushed with air prior to sample collection at each location. Separate syringes were used for samples collected from floors used for living space and for samples collected from the garage. Samples were submitted to ORTECH Corporation in Mississauga, Ontario for gas chromatograph analysis.

Ambient air samples were collected from locations throughout the buildings, similar to PFT testing. Sample locations are listed in **Table A2-1, Appendix 2**. The sample collected at the elevator sump pit in which the tracer was injected, was collected from the top of the sump pit. This was because access to lower levels of the elevator sump pits was restricted. As $SF_6$ gas is heavier than air, $SF_6$ concentrations at the bottom of the sump pit were assumed to approach 100%.

Concentrations detected through analysis were normalized as per the procedure described in **section 4.2.5**. Normalized concentrations from winter and summer testing were compared to evaluate the effect on gas transfer of seasonal changes and ventilation.

Ambient conditions such as pressure and temperature were measured during the summer and winter rounds of testing to evaluate the effect of building temperature and pressure changes on the distribution of contaminants in the building. The testing schedule is presented in **Appendix 1**.

# 5.0 RESULTS

## 5.1 Dust

A full report of the literature search conducted to evaluate the risk associated with fugitive dust in high-rise apartment buildings is presented in **Appendix 3**. The following points summarize the major findings of the literature search:

- there is a lack of available information concerning the make-up of dusts migrating from contaminated soils;

- no specific information concerning dust transmission into apartment buildings was found;

- contaminate pathways in a high-rise apartment building scenario are limited to the inhalation or ingestion of dust entering the apartment building envelope[2];

- the data base concerning health risks resulting from fugitive dust is weak[3];

- it is generally believed that dust concentrations in the indoor environment are less than dust concentrations found in the outside environment when no major sources of indoor dust are present[4,5]; and

- a covering of material of low erodibility such as clay, a significantly vegetated soil cover, or asphalt or concrete paving is thought to reduce the amount of fugitive dust able to escape from the contaminated site to an insignificant amount[2].

The literature search found that the number of transfer pathways possible in the high-rise apartment scenario are limited and that these transfer pathways are hindered by the building envelope, although not eliminated. Control of hazard emission and risk should be possible through the use of covers with low erodibilty.

## 5.2 Evaluation of Gas Transport Pathways

### 5.2.1 Normalized Concentrations

The normalized PFT gas concentrations measured in all areas of Buildings A, B and C during summer and winter testing are presented in **Tables 5.2.1**, **5.2.2** and **5.2.3**, respectively. The normalized concentrations for the living spaces of the three buildings are also presented graphically in **Figures 5.2.1**, **5.2.2** and **5.2.3**. Raw data showing the results of CAT analysis for PFT concentrations can be found in **Appendix 4**.

Seasonal Variations

Overall gas transfer patterns were similar for both winter and summer testing. As can be seen in **Figures 5.2.1 - 5.2.3**, significant gas transfer pathways exist regardless of the season. Results show that in the buildings studied, transfer paths for gaseous phase contaminants are present in varying degrees and

**TABLE 5.2.1**
**NORMALIZED RESULTS OF PFT TESTING**
**BUILDING A**

| Detection Location | | Results of Normalized PFT Detection from 3 Emmission Sources | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Sump Pit | | | Floor Drain | | | Pipe Entrance | | |
| Floor/Unit | Area | Winter | Summer | Ratio | Winter | Summer | Ratio | Winter | Summer | Ratio |
| 1506 | living room | 2.3000 | 0.7560 | 3.042 | 0.2420 | 0.1520 | 1.592 | 0.0730 | 0.1060 | 0.689 |
| 1502 | living room | 1.1100 | 0.0798 | 13.910 | 0.1310 | 0.0921 | 1.422 | 0.0513 | 0.0564 | 0.910 |
| 1500 | hallway | 3.2600 | 1.1100 | 2.937 | 0.3260 | 0.1730 | 1.884 | 0.6610 | 0.0994 | 6.650 |
| 709 | living room | 0.0369 | 0.0722 | 0.511 | 0.0155 | 0.0644 | 0.241 | 0.0414 | 0.0468 | 0.885 |
| 701 | living room | 0.0370 | 0.1020 | 0.363 | 0.0155 | 0.0955 | 0.162 | 0.0418 | 0.6620 | 0.063 |
| 700 | hallway | 0.0458 | 0.3110 | 0.147 | 0.1140 | 0.1210 | 0.942 | 0.0767 | 0.0791 | 0.970 |
| 109 | living room | 0.0068 | 0.3750 | 0.018 | 0.3070 | 0.4980 | 0.616 | 0.1840 | 0.6620 | 0.278 |
| 103 | living room | 0.0073 | 0.0867 | 0.084 | 0.4150 | 0.1490 | 2.785 | 0.3380 | 0.1090 | 3.101 |
| 100 | hallway | - | 0.5610 | - | - | 0.1920 | - | - | 0.1840 | - |
| garage | elevator room | 0.8540 | 1.6100 | 0.530 | 0.3250 | 2.6600 | 0.122 | 0.6090 | 1.5000 | 0.406 |
| garage | north drain | 23.9000 | 6330.0000 | 0.004 | 22800.0000 | 316000.0000 | 0.072 | 127.0000 | 10300.0000 | 0.012 |
| garage | pipe entrance | 28.1000 | 72.9000 | 0.385 | 92.4000 | 362.0000 | 0.255 | 53000.0000 | 2090.0000 | 25.359 |
| garage | south drain | 27.1000 | 646.0000 | 0.042 | 13500.0000 | 242000.0000 | 0.056 | 133.0000 | 985.0000 | 0.135 |
| garage | sump pit | 9120.0000 | 69700.0000 | 0.131 | 66.1000 | 1780.0000 | 0.037 | 9.7500 | 2280.0000 | 0.004 |
| garage | sump room | 1.5100 | 169.0000 | 0.009 | 1.7600 | 173.0000 | 0.010 | 1.2900 | 129.0000 | 0.010 |

| Winter Testing Normalizing Concentrations (NC) (pL/L or ppt) | |
|---|---|
| Sump Pit | 1.3061 |
| Floor Drain | 0.2706 |
| Pipe Entrance | 0.2439 |

| Summer Testing Normalizing Concentrations (NC) (pL/L or ppt) | |
|---|---|
| Sump Pit | 1.6495 |
| Floor Drain | 1.3674 |
| Pipe Entrance | 0.4677 |

**TABLE 5.2.2**
**NORMALIZED RESULTS OF PFT TESTING**
**BUILDING B**

| **Detection Location** | | **Results of Normalized PFT Detection from 3 Emmission Sources** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Sump Pit | | | Floor Drain | | | Pipe Entrance | | |
| Floor/Unit | Area | Winter | Summer | Ratio | Winter | Summer | Ratio | Winter | Summer | Ratio |
| 2007 | living room | 0.1990 | 0.0811 | 2.454 | 0.2790 | 0.2110 | 1.322 | 0.0696 | 0.1590 | 0.438 |
| 2002 | living room | 0.0847 | 0.0571 | 1.483 | 0.0000 | 0.1720 | 0.000 | 0.0573 | 0.1230 | 0.466 |
| 2000 | hallway | 0.1990 | 0.0296 | 6.723 | 0.2790 | 0.1350 | 2.067 | 0.1610 | 0.0903 | 1.783 |
| 1006 | living room | 0.0263 | 0.0934 | 0.282 | 0.0000 | 0.2230 | 0.000 | 0.0267 | 0.1570 | 0.170 |
| 1001 | living room | 0.0115 | 0.0765 | 0.150 | 0.0000 | 0.1960 | 0.000 | 0.0136 | 0.1400 | 0.097 |
| 1000 | hallway | 0.0170 | 0.0230 | 0.739 | 0.0000 | 0.1290 | 0.000 | 0.0168 | 0.0852 | 0.197 |
| 100 | office | 0.0024 | 0.0781 | 0.031 | 0.0000 | 0.2270 | 0.000 | 0.0317 | 0.1550 | 0.205 |
| 100 | hallway | 0.0876 | 0.0441 | 1.986 | 0.1110 | 0.1530 | 0.725 | 0.0999 | 0.1000 | 0.999 |
| 100 | guest suite | 0.0307 | 0.1270 | 0.242 | 0.2530 | 0.2990 | 0.846 | 0.0159 | 0.2040 | 0.078 |
| garage | elevator room | 1.5400 | 95.4000 | 0.016 | 391.0000 | 1110.0000 | 0.352 | 2.9800 | 532.0000 | 0.006 |
| garage | floor drain | 2570.0000 | 61900.0000 | 0.042 | 153000.0000 | 5730000.0000 | 0.027 | 4160.0000 | 176000.0000 | 0.024 |
| garage | pipe entrance | 46.6000 | 3010.0000 | 0.015 | 2710.0000 | 8930.0000 | 0.303 | 4480.0000 | 273000.0000 | 0.016 |
| garage | sump pit | 385000.0000 | 34800.0000 | 11.063 | 2240.7380 | 4860.0000 | 0.461 | 1080.0000 | 479.0000 | 2.255 |
| travel blank | | 0.0000 | 0.0007 | 0.000 | 0.0000 | 0.0010 | 0.000 | 0.0000 | 0.0000 | - |

| Winter Testing<br>Normalizing Concentrations (NC)<br>(pL/L or ppt) | |
|---|---|
| Sump Pit | 1.0992 |
| Floor Drain | 0.1328 |
| Pipe Entrance | 1.2502 |

| Summer Testing<br>Normalizing Concentrations (NC)<br>(pL/L or ppt) | |
|---|---|
| Sump Pit | 1.2598 |
| Floor Drain | 0.8385 |
| Pipe Entrance | 1.0316 |

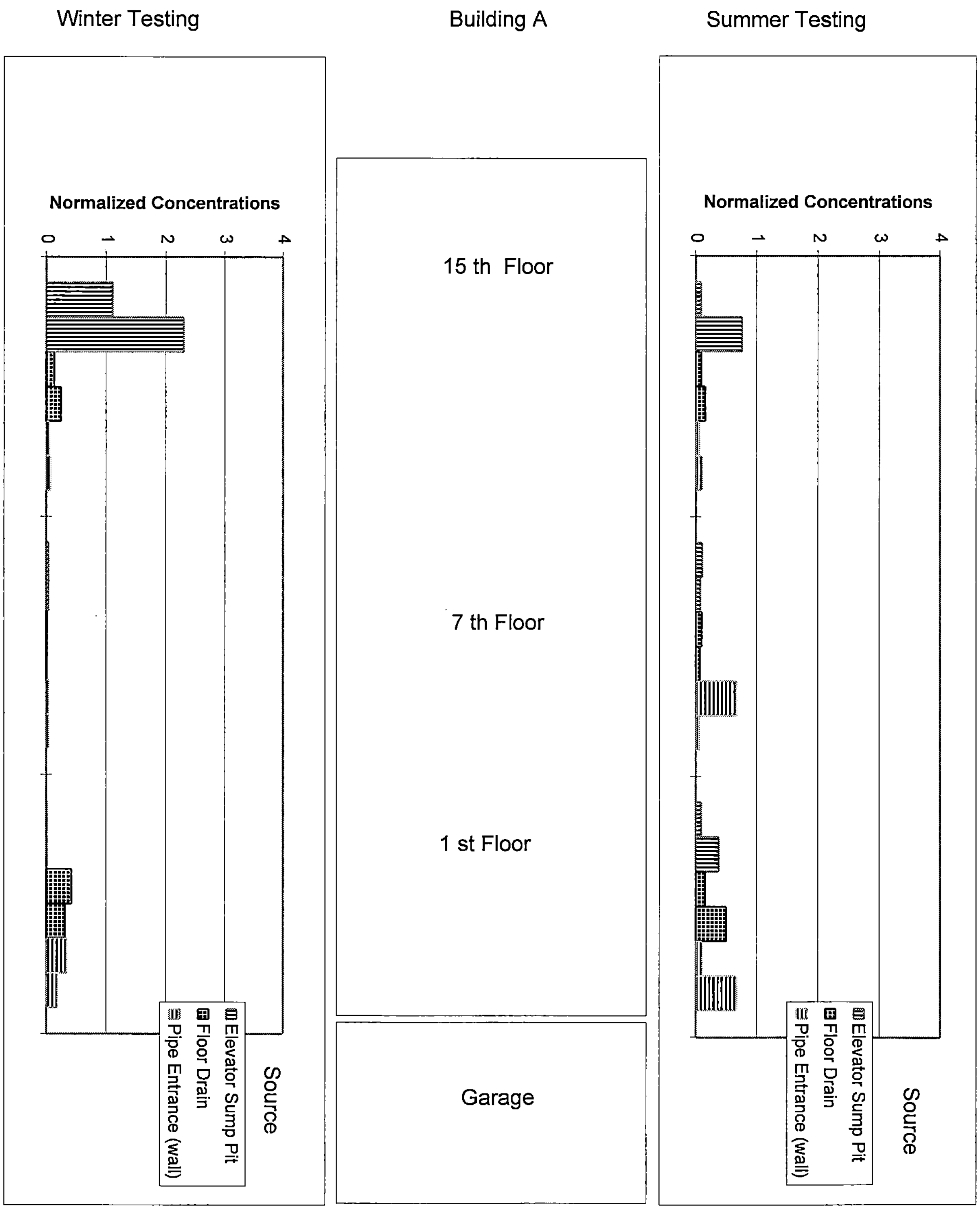
**TABLE 5.2.3**
**NORMALIZED RESULTS OF PFT TESTING**
**BUILDING C**

| **Detection Location** | | **Results of Normalized PFT Detection from 3 Emmission Sources** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Elevator Sump Pit | | | Pipe Entrance | | | General Sump Pit | | |
| Floor/Unit | Area | Winter | Summer | Ratio | Winter | Summer | Ratio | Winter | Summer | Ratio |
| 1810 | living room | 0.6900 | 0.1990 | 3.467 | 3.2000 | 0.1490 | 21.477 | 0.3080 | 0.0397 | 7.758 |
| 1803 | living room | 3.1400 | 1.2300 | 2.553 | 2.8900 | 0.2830 | 10.212 | 0.4560 | 1.5000 | 0.304 |
| 1800 | hallway | 2.7400 | 1.6300 | 1.681 | 3.4400 | 0.4350 | 7.908 | 0.4140 | 0.1330 | 3.113 |
| 912 | living room | 0.0366 | 0.0951 | 0.385 | 0.5120 | 0.0967 | 5.295 | 0.0947 | 0.0288 | 3.288 |
| 903 | living room | 0.0529 | 0.0582 | 0.909 | 1.0700 | 0.0649 | 16.487 | 0.1680 | 0.0178 | 9.438 |
| 900 | hallway | 0.2530 | - | - | 3.9600 | - | - | 0.5030 | - | - |
| 100 | office | 0.0193 | 0.0699 | 0.276 | 6.2300 | 1.0900 | 5.716 | 0.4500 | 0.2080 | 2.163 |
| 100 | laundry | 0.0243 | 0.0815 | 0.298 | 6.2300 | 0.3840 | 16.224 | 1.0100 | 0.1120 | 9.018 |
| 100 | hallway | - | 0.2470 | - | - | 0.3980 | - | - | 0.0882 | - |
| garage | elevator sump | 420.0000 | 12300.0000 | 0.034 | 12.0000 | 1600.0000 | 0.008 | 4.4200 | 981.0000 | 0.005 |
| garage | general sump | 13.0000 | 903.0000 | 0.014 | 10.1000 | 3570.0000 | 0.003 | 45700.0000 | 183000.0000 | 0.250 |
| garage | pipe entrance | 0.6450 | 333.0000 | 0.002 | 44.1000 | 2330.0000 | 0.019 | 4.4200 | 907.0000 | 0.005 |
| garage | sump room | 13.4000 | 364.0000 | 0.037 | 1.6100 | 1890.0000 | 0.001 | 4880.0000 | 9710.0000 | 0.503 |

| Winter Testing<br>Normalizing Concentrations (NC)<br>(pL/L or ppt) | |
|---|---|
| Elevator Sump Pit | 0.886 |
| Pipe Entrance | 0.107 |
| General Sump | 1.0076 |

| Summer Testing<br>Normalizing Concentrations (NC)<br>(pL/L or ppt) | |
|---|---|
| Elevator Sump Pit | 1.1392 |
| Pipe Entrance | 0.7583 |
| General Sump | 0.9329 |

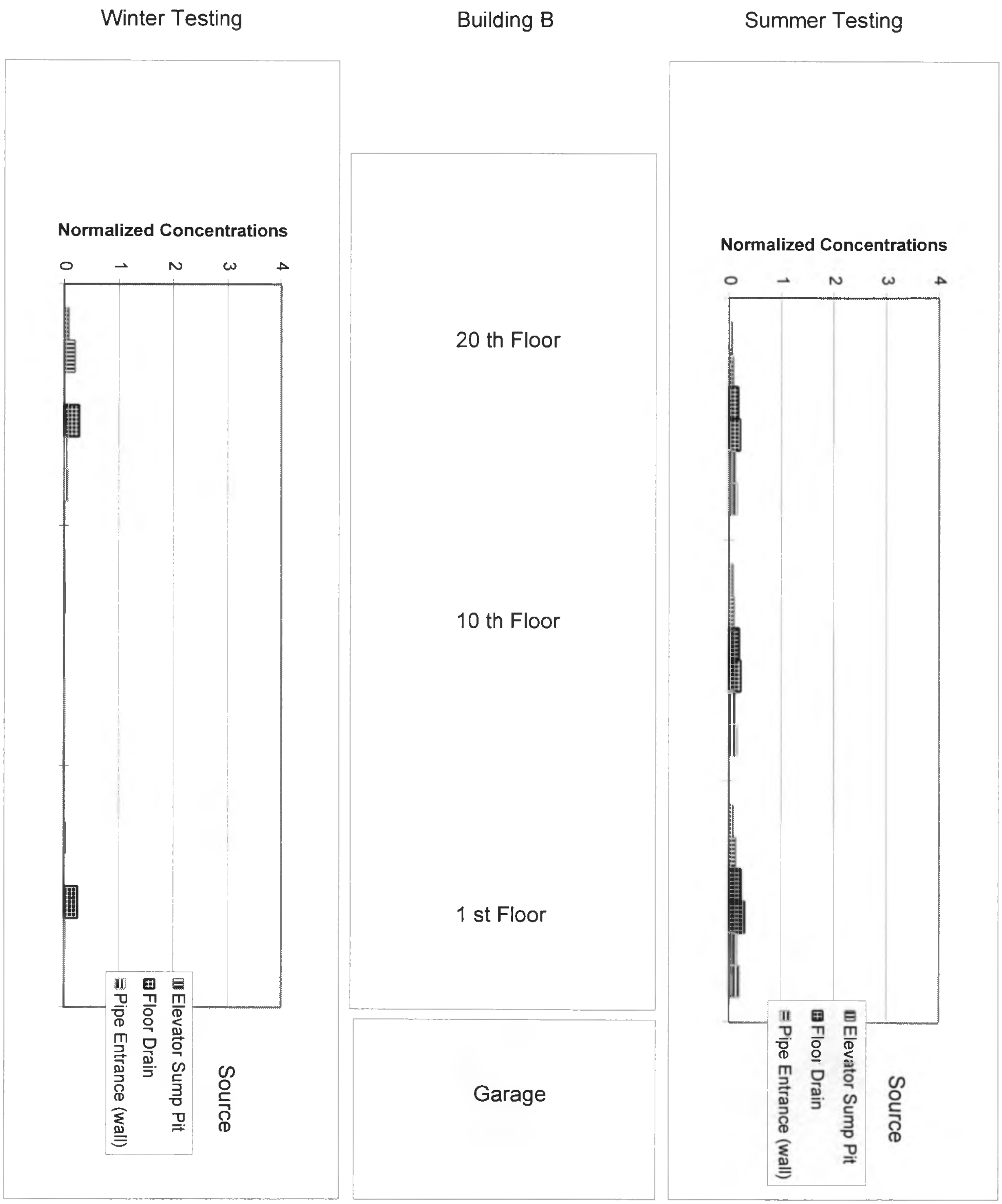
# Figure 5.2.1
## Normalized PFT Concentrations in Living Space




Note: A normalized concentration greater than 1 shows a strong transfer path between the emission source and the receptor. Two concentrations are given for every source.

# Figure 5.2.2

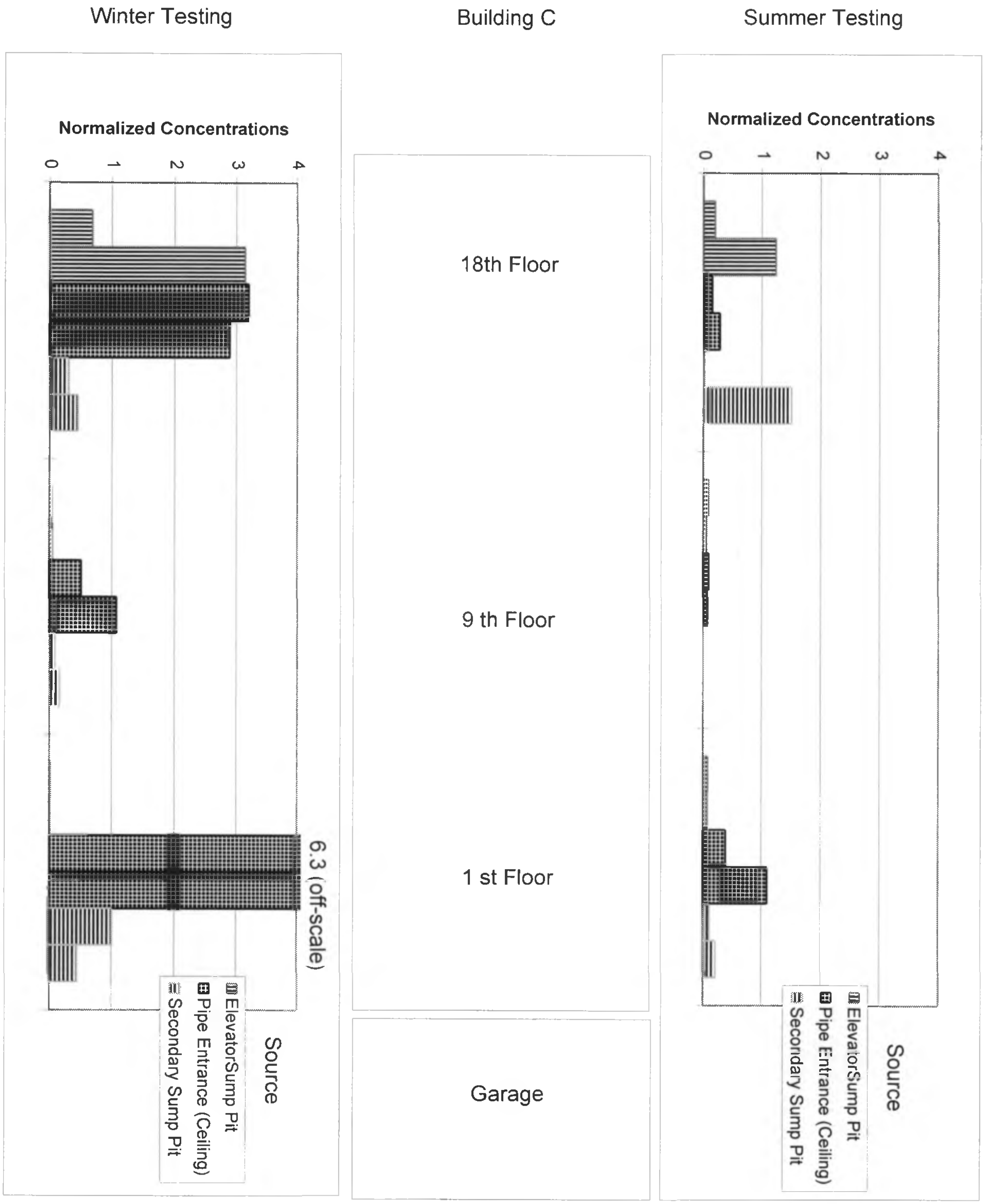
Normalized PFT Concentrations in Living Space




Note: A normalized concentration greater than 1 shows a strong transfer path between the emission source and the receptor. Two concentrations are given for every source.

# Figure 5.2.3

## Normalized PFT Concentrations in Living Space




Note: A normalized concentration greater than 1 shows a strong transfer path between the emission source and the receptor. Two concentrations are given for every source.

patterns in all seasons and are not just winter-time stack-induced phenomena. During summer testing, greater normalized concentrations of tracer were detected in the garage areas of all buildings, as compared to the winter test results. Concentrations of PFTs detected in the living spaces increased or decreased depending on the building and the sample location.

Building A

The most significant gas transfer pathway in building A was observed during winter testing. This pathway was between the emission source located in the elevator sump and the upper floor living spaces. The highest normalized concentration measured on this floor was 2.3, which is indicative of a relatively strong transfer pathway. This compared with the summer value of 0.76. During both summer and winter testing, pathways were found to exist to the ground floor living spaces. These were slightly more significant during summer testing, specifically from the emission source located at the pipe entrance. There was also a minor pathway observed between this source and the seventh floor during summer testing, which was not observed during winter testing.

Building B

Significant pathways were not observed from any emission source to living spaces in this building for both summer and winter testing. In general, normalized concentrations at all floors were slightly greater during summer testing. During winter testing, the only observable pathways were to the upper and ground floors. It is suspected that the transfer paths found in Building B were not as strong as those detected in the other two buildings because of a more effective central ventilation system.

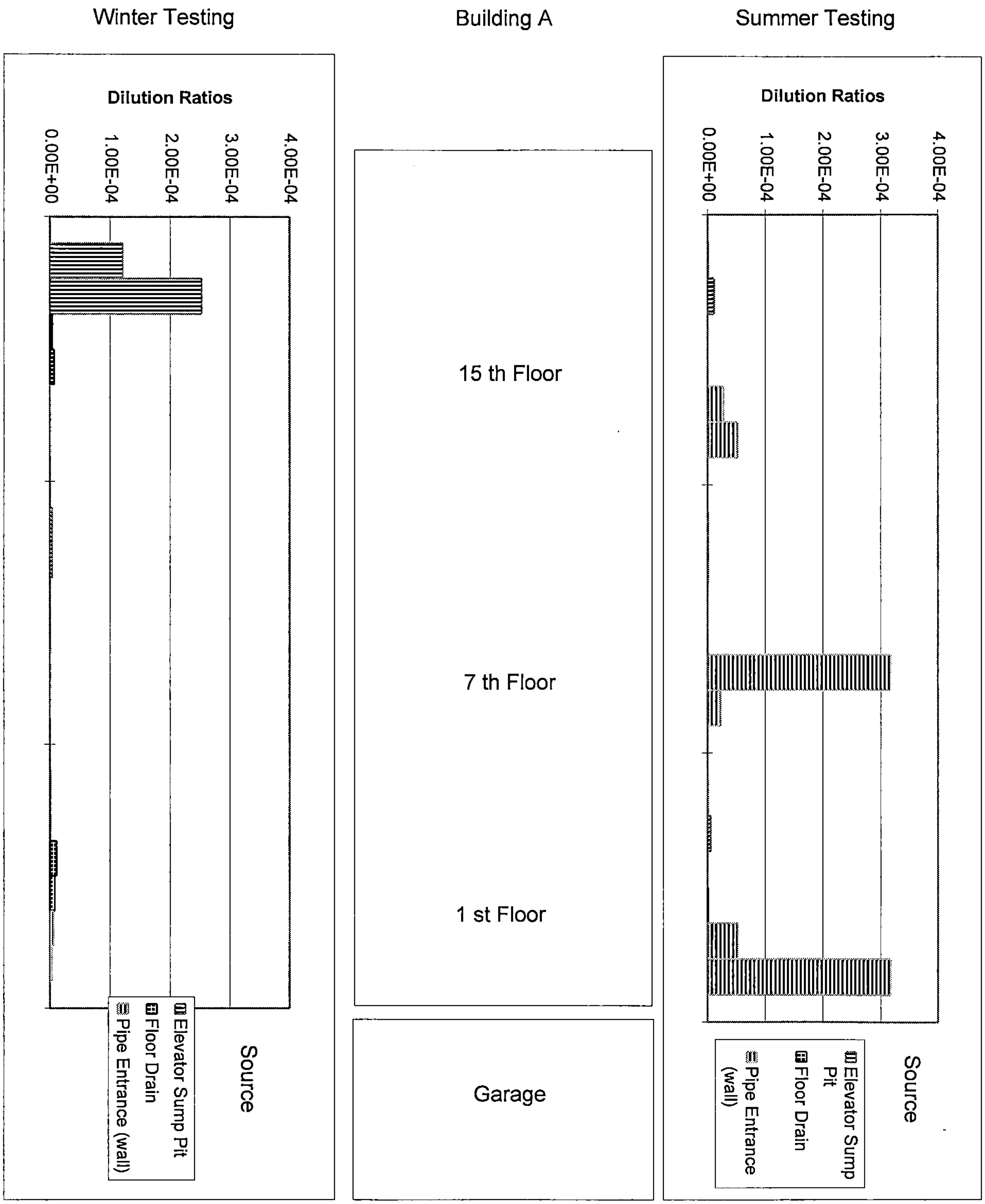
Building C

Of the 3 buildings studied, the most significant pathways were found to occur in Building C, as can be seen in **Figure 5.2.3**. This building also showed that the transfer pathways were more pronounced in winter. The most significant emission source during winter testing was the source located near the pipe entrance in the garage ceiling slab. Normalized concentrations from this emission source of 3.2, 1.1 and 6.2 were measured on the eighteenth, ninth and ground floors, respectively. Normalized concentrations were also elevated in upper floor living spaces due to the emission source located in the elevator sump pit, and had values of 3.1 and 1.2 for summer and winter, respectively. Important pathways were also detected between the emission source located in the secondary sump pit and the upper floor during summer testing, and the ground floor during winter testing. The normalized concentrations for these two were 1.5 and 1.0, respectively.

### 5.2.2 Dilution Ratios

The dilution of the tracer gases between the source and the living space was also examined. The results of these calculations are presented in **Figures 5.2.4**, **5.2.5** and **5.2.6**. Related tables are presented in

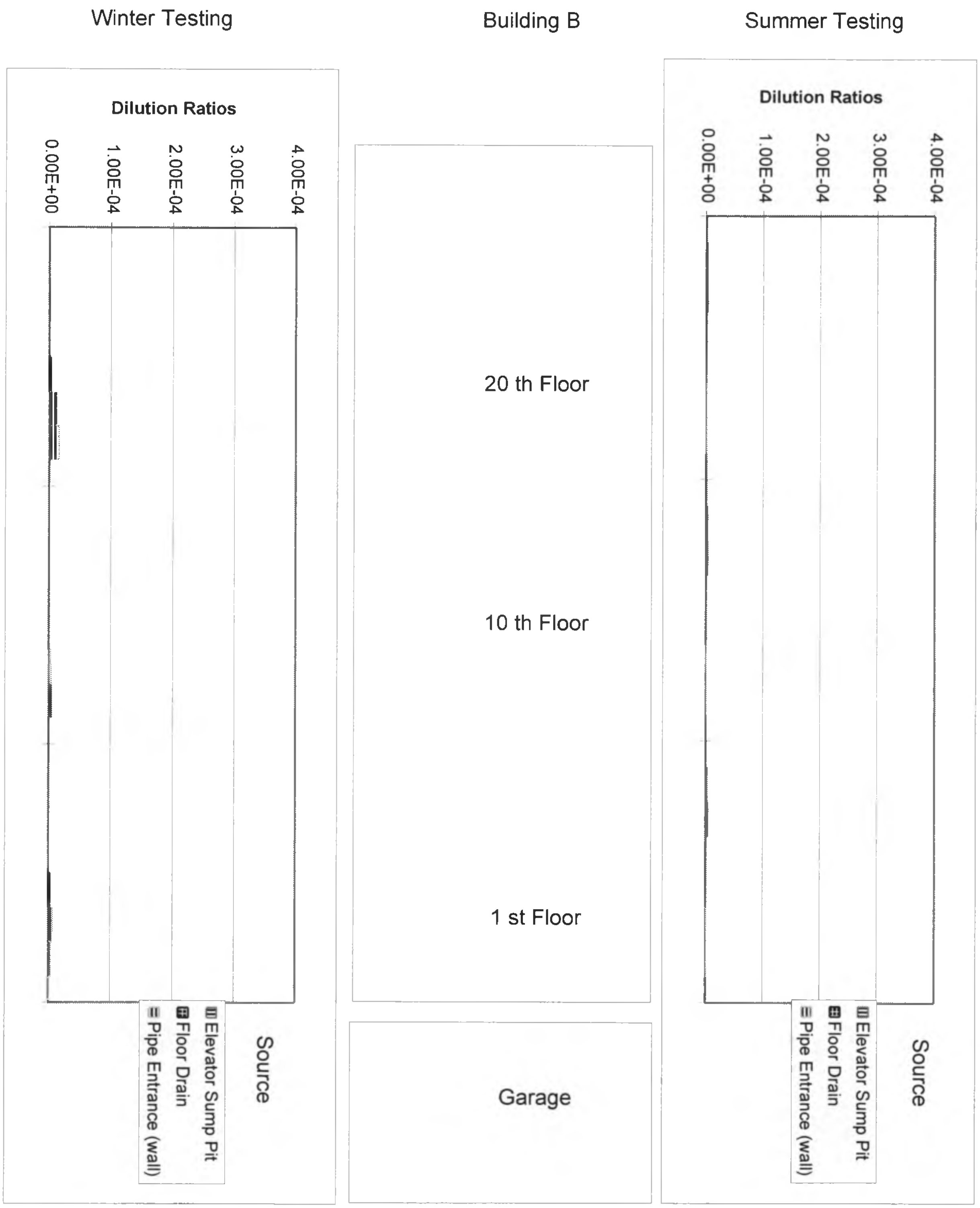
Figure 5.2.4
PFT Dilution Ratios in Living Space




Note: The dilution ratio is the concentration of the tracer gas measured at the receptor divided by the concentration at the emission source. Two concentrations are given for every source.

# Figure 5.2.5

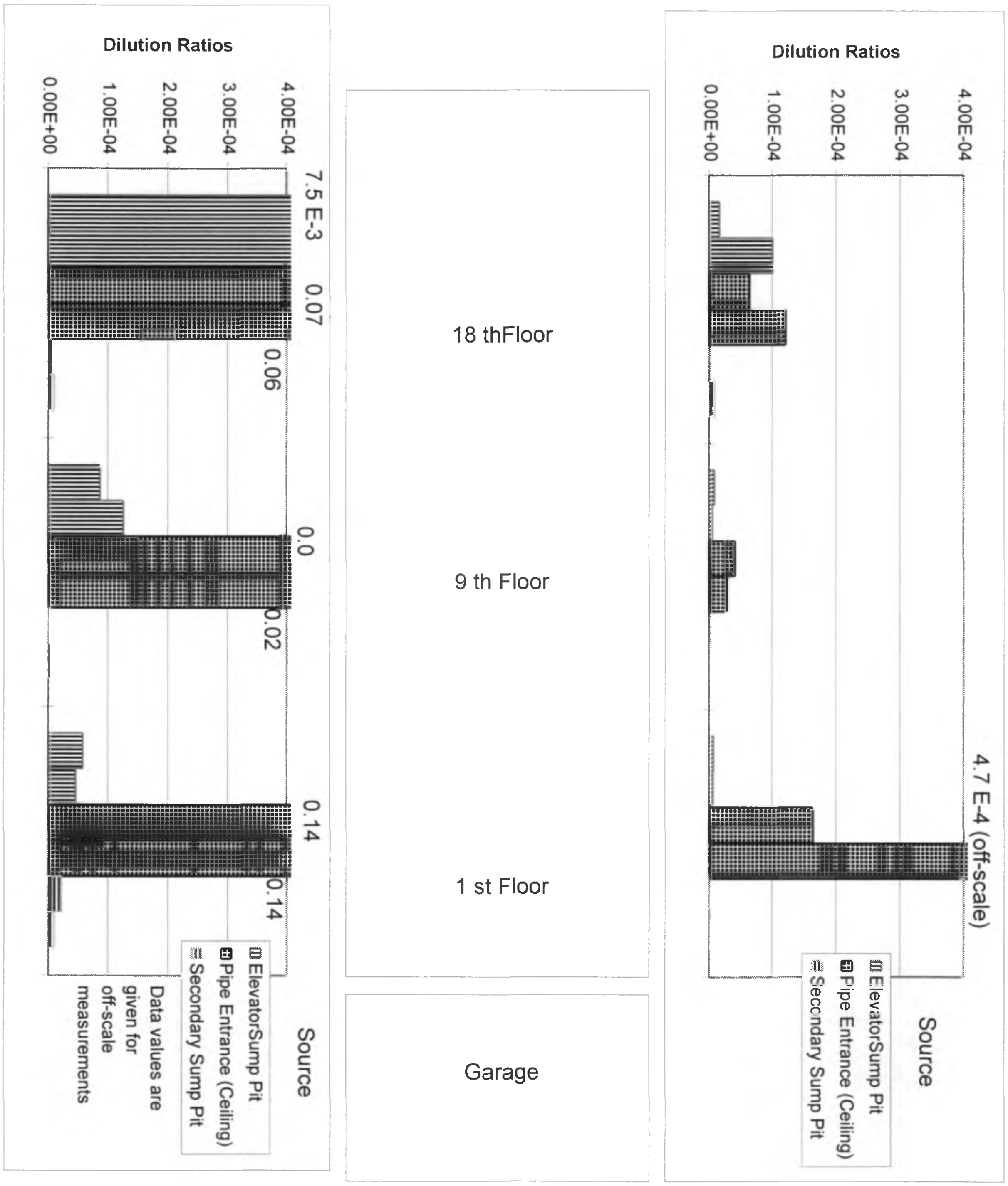
PFT Dilution Ratios in Living Space




Note: The dilution ratio is the concentration of the tracer gas measured at the receptor divided by the concentration at the emission source. Two concentrations are given for every source.

## Figure 5.2.6
PFT Dilution Ratios in Living Space

Winter Testing | Building C | Summer Testing




Note: The dilution ratio is the concentration of the tracer gas measured at the receptor divided by the concentration at the emission source. Two concentrations are given for every source.

**Appendix 4**. Analysis of Figures **5.2.4-5.2.6** confirms that the dilution ratio data is internally consistent with the normalized concentration data.

In general, during the summer and winter testing, reductions between 3 to 7 orders of magnitude were found between PFT concentrations at emission sources and living spaces. Building B displayed the largest reductions in concentrations (6 to 8 orders of magnitude). The most notable exception was during winter testing in Building C. The reduction in concentration between the emission source located at the ceiling pipe entrance and the ground floor living area was only one order of magnitude.

### 5.2.3 Experimental Error

During laboratory analysis, small concentrations of tracers which were only used in Building A were detected in the CAT samplers from Building B, and *vice versa*. Based on the levels of the tracers detected, it is approximated that the PFT data reported for the summer round of testing contains a 20% to 30% error. This level of error is acceptable considering the goal of the study, i.e. to identify the presence and magnitude of gas transfer pathways in high-rise apartment buildings.

No detectable levels of tracer were found in the analysis of the travel blank CAT sampler from the winter round of testing. This indicated that the CAT samplers used during winter testing were not contaminated during transport.

The presence of three tracer types was detected in the travel blank CAT from the summer round of testing. Concentrations detected were two orders of magnitude lower than the concentrations measured in exposed CAT samplers. The PFT presence detected in the travel CAT sampler gives a reflection of the accuracy of the PFT concentrations detected in the CATs installed in the subject buildings. The level of contamination observed in the travel CAT partially explains the additional tracer types detected, and the increased level of error in results from the summer round of testing.

## 5.3 Ventilation System Effects

The effect of ventilation systems on gas transfer pathways was investigated using sulphur hexafluoride ($SF_6$) tracer gas (see **section 4.3**). Winter testing was conducted in all three of the subject buildings and summer testing was conducted for Building B. Analytical results from the winter round of testing are presented in **Tables 5.3.1**, **5.3.2** and **5.3.3**, and summer testing results are presented in **Table 5.3.4**. Normalized results are also displayed along with the $SF_6$ concentration ratios for ventilation off and normal operation scenarios.

**TABLE 5.3.1**

**Effect of Ventilation Systems**
**Winter SF6 Test Results**
**Building A**

| Floor / Unit | Location | SF6 Concentration (ppb) | | Normalized Concentration | | Ventilation Off/On Ratio |
|---|---|---|---|---|---|---|
| | | Ventilation Off | Ventilation On | Ventilation Off | Ventilation On | |
| 1506 | living room | 560.00 | 790.00 | 0.625 | 0.882 | 0.709 |
| 1502 | living room | 1070.00 | 1130.00 | 1.194 | 1.261 | 0.947 |
| 1500 | hallway | 1850.00 | 2480.00 | 2.065 | 2.768 | 0.746 |
| 1500 | hallway | 1860.00 | 1690.00 | 2.076 | 1.886 | 1.101 |
| 709 | living room | 0.31 | 9.00 | 0.000 | 0.010 | 0.034 |
| 701 | living room | 1.00 | 4.70 | 0.001 | 0.005 | 0.213 |
| 700 | hallway | 37.50 | 65.40 | 0.042 | 0.073 | 0.573 |
| 109 | living room | nd | 0.40 | nd | 0.000 | - |
| 103 | living room | 0.10 | 2.60 | 0.000 | 0.003 | 0.038 |
| 100 | hallway | 0.60 | 8.90 | 0.001 | 0.010 | 0.067 |
| 100 | hallway | 1.30 | 1.30 | 0.001 | 0.001 | 1.000 |
| garage | floor drain | nd | 0.35 | nd | 0.000 | - |
| garage | sump pit | 8500.00 | 6740.00 | 9.487 | 7.522 | 1.261 |
| garage | sump room | 58.00 | 9.40 | 0.065 | 0.010 | 6.170 |

nd = not detected
Normalizing concentration 896 ppb

TABLE 5.3.2

**Effect of Ventilation Systems**
**Winter SF6 Test Results**
**Building B**

| Floor / Unit | Location | SF6 Concentration (ppb) | | Normalized Concentration | | Ventilation Off/On Ratio |
|---|---|---|---|---|---|---|
| | | Ventilation Off | Ventilation On | Ventilation Off | Ventilation On | |
| 2007 | living room | 3610.00 | 970.00 | 5.142 | 1.382 | 3.722 |
| 2002 | living room | 2100.00 | 520.00 | 2.991 | 0.741 | 4.038 |
| 2000 | hallway | 4390.00 | 5.30 | 6.254 | 0.008 | 828.302 |
| 2000 | hallway | 4820.00 | 240.00 | 6.866 | 0.342 | 20.083 |
| 1006 | living room | 4.70 | 3.10 | 0.007 | 0.004 | 1.516 |
| 1001 | living room | 1.10 | 8.30 | 0.002 | 0.012 | 0.133 |
| 1000 | hallway | 1330.00 | 2.20 | 1.895 | 0.003 | 604.545 |
| 100 | guest suite | 6.90 | 7.00 | 0.010 | 0.010 | 0.986 |
| 100 | hallway | 260.00 | 2.00 | 0.370 | 0.003 | 130.000 |
| 100 | hallway | 490.00 | 330.00 | 0.698 | 0.470 | 1.485 |
| 100 | office | 2.10 | 5.90 | 0.003 | 0.008 | 0.356 |
| garage | parking area | 7640.00 | 8320.00 | 10.883 | 11.852 | 0.918 |
| garage | sump area | 8210.00 | 8480.00 | 11.695 | 12.080 | 0.968 |
| garage | sump pit | 11660.00 | 12150.00 | 16.610 | 17.308 | 0.960 |

nd = not detected
Normalizing concentration 702 ppb

**TABLE 5.3.3**

**Effect of Ventilation Systems**
**Winter SF6 Test Results**
**Building C**

| Floor / Unit | Location | SF6 Concentration (ppb) | | Normalized Concentration | | Ventilation Off/On Ratio |
|---|---|---|---|---|---|---|
| | | Ventilation Off | Ventilation On | Ventilation Off | Ventilation On | |
| 1810 | living room | 240.00 | 77.80 | 0.342 | 0.111 | 3.085 |
| 1803 | living room | 390.00 | 410.00 | 0.556 | 0.584 | 0.951 |
| 1800 | hallway | 720.00 | 960.00 | 1.026 | 1.368 | 0.750 |
| 1800 | hallway | 680.00 | 1180.00 | 0.969 | 1.681 | 0.576 |
| 912 | living room | 1.30 | 0.50 | 0.002 | 0.001 | 2.600 |
| 903 | living room | 0.70 | 0.10 | 0.001 | 0.000 | 7.000 |
| 900 | hallway | 72.00 | 3.00 | 0.103 | 0.004 | 24.000 |
| 100 | hallway | 47.10 | 19.10 | 0.067 | 0.027 | 2.466 |
| 100 | hallway | 15.70 | 44.40 | 0.022 | 0.063 | 0.354 |
| 100 | laundry | 25.80 | 10.60 | 0.037 | 0.015 | 2.434 |
| 100 | office | 24.40 | 3.30 | 0.035 | 0.005 | 7.394 |
| garage | elevator sump area | 98.90 | 160.00 | 0.141 | 0.228 | 0.618 |
| garage | elevator sump pit | 4150.00 | 730.00 | 5.912 | 1.040 | 5.685 |
| garage | sump area | 10.30 | 9.00 | 0.015 | 0.013 | 1.144 |
| garage | sump pit | 0.33 | 1.40 | 0.000 | 0.002 | 0.236 |

nd = not detected
Normalizing concentration 702 ppb

TABLE 5.3.4

**Effect of Ventilation Systems**
**Summer SF6 Test Results**
**Building B**

| Floor / Unit | Location | SF6 Concentration (ppb) | | Normalized Concentration | | Ventilation Off/On Ratio |
|---|---|---|---|---|---|---|
| | | Ventilation Off | Ventilation On | Ventilation Off | Ventilation On | |
| 2007 | living room | 440.00 | 130.00 | 0.627 | 0.185 | 3.385 |
| 2002 | living room | 390.00 | 34.00 | 0.556 | 0.048 | 11.471 |
| 2000 | hallway | 530.00 | 0.15 | 0.755 | 0.000 | 3533.333 |
| 2000 | hallway | 490.00 | 2.00 | 0.698 | 0.003 | 245.000 |
| 1006 | living room | 230.00 | 5.00 | 0.328 | 0.007 | 46.000 |
| 1001 | living room | 30.00 | 10.00 | 0.043 | 0.014 | 3.000 |
| 1000 | hallway | 370.00 | 0.20 | 0.527 | 0.000 | 1850.000 |
| 100 | guest suite | 55.00 | 0.70 | 0.078 | 0.001 | 78.571 |
| 100 | hallway | 280.00 | 9.00 | 0.399 | 0.013 | 31.111 |
| 100 | hallway | 190.00 | 0.40 | 0.271 | 0.001 | 475.000 |
| 100 | office | 100.00 | 10.00 | 0.142 | 0.014 | 10.000 |
| garage | parking area | 3900.00 | 2700.00 | 5.556 | 3.846 | 1.444 |
| garage | sump area | 3900.00 | 4800.00 | 5.556 | 6.838 | 0.813 |
| garage | sump pit | 3400.00 | 6900.00 | 4.843 | 9.829 | 0.493 |

nd = not detected
Normalizing concentration 702 ppb

Ventilation-Off Scenario (Winter Testing)

In the ventilation-off scenario, normalized $SF_6$ gas concentrations as high as 1.2, 5.1, and 0.6 times the fully mixed scenario were found in upper-floor apartments in Buildings A, B, and C. In general, $SF_6$ concentrations were significantly higher in the hallways than in the apartments. Concentrations were also much lower in the mid to ground level living spaces, with a maximum normalized concentration of 0.04 detected in Building C. In Buildings A and C, concentrations of $SF_6$ detected in the garage and sump room were low relative to the top of the sump pit. However, in Building B, concentrations in the garage area, outside of the sump pit, were similar to the sump pit measurements.

Normal-Ventilation Scenario (Winter Testing)

Little change was detected in the transport pathways of the $SF_6$ tracer gas in Buildings A and C when ventilation systems were reactivated. Tracer gas concentrations in Building B, however, decreased significantly throughout the building when ventilation systems (garage exhaust, make up air and central suite exhaust) were activated. For example, $SF_6$ concentrations measured in the upper floor hallways dropped by 20 - 830 times. On the other hand, concentrations in the upper floor apartments only dropped by 3 - 4 times, and levels were much higher than those from PFT testing. It is suspected that this may be because equilibrium was not completely reached in these apartments. It should be noted that Building B is the only one of the three subject buildings with a central exhaust ventilation system.

In the normal-ventilation scenario, normalized concentrations of 1.3, 1.4 and 0.6 were detected in the upper floor apartments in Buildings A, B and C, respectively, while the maximum normalized concentration detected on mid and lower-level living spaces was 0.02. With the exception of the elevated concentrations in the upper floor apartments in Building B, the magnitude and pattern of gas transport in the normal-ventilation scenario are comparable to results obtained from the PFT testing in which the elevator sump pit was the source. (This PFT data was collected over a three week period with normal-ventilation operation).

Seasonal Variation

Due to the significance of the ventilation system in influencing the gas transport pathways in Building B, $SF_6$ testing was also conducted during the summer round of testing. Results of summer testing are presented in **Table 5.3.4**. In general, the transfer of $SF_6$ gas from the elevator sump pit to the living space was significantly reduced during the summer round of testing. This was true for both ventilation situations. In the ventilation-off situation, the maximum normalized concentration detected in the living space was 0.6. When ventilation systems were activated, a maximum normalized concentration of 0.2 was detected in the upper floor living space.

Experimental Error

During all testing rounds, extra air samples were collected for $SF_6$ analysis to test whether or not equilibrium of tracer gas concentrations had been achieved for each ventilation scenario. A chart comparing values used for equilibrium evaluation is given in **Table A5-1**, in **Appendix 5**. A certain level of variation in the readings was expected due to the effect of elevator usage on the measurements taken in the corridor. In all of the ventilation-off testing rounds, concentrations measured before and after the sampling round were fairly similar and indicated an acceptable level of equilibrium. A greater variation was found in the equilibrium readings in the normal-ventilation scenario. No specific pattern was established with respect to continued flushing or tracer gas build-up. However, it is possible that total equilibrium was not completely reached in all buildings in the normal ventilation scenario.

## 5.4 Ambient Conditions

Ambient outdoor and building conditions were measured during each testing round at each building. Temperatures and differential pressures recorded during testing are listed in **Appendix 6**. The pressure information collected from Buildings A and B during the winter round of testing is limited to the ventilation-off scenario. During the summer round of testing, ventilation systems were not deactivated in Buildings A and C. Apart from building ventilation systems, apartments were also ventilated by residents who opened windows or balcony doors, operated manually controlled fans, or in some cases had private air-conditioning units.

Analysis of the pressure differential data presented in **Appendix 6** indicated that no conclusions could be drawn concerning changes in building pressures resulting from the deactivation of the ventilating systems.

Temperature information collected during the winter testing period displays a large difference in temperature between inside and outside building conditions. This temperature differential will create stack forces in high-rise apartment buildings.

# 6.0 DISCUSSION

## 6.1 Risk Associated with Fugitive Dust

For a risk to be present there must be a hazard, exposure to the hazard, and a receptor of the hazard. When examining the risk associated with fugitive dust in high-rise apartment buildings, both a hazard and a receptor are assumed to exist. The exposure pathway was investigated to determine if a significant risk to high-rise apartment dwellers can be attributed to dust from contaminated lands.

The literature search found that the number of transfer pathways possible in the high-rise apartment scenario are limited and that these transfer pathways are hindered by the building envelope, although not eliminated. Control of hazard emission and risk should be possible through the use of covers with low erodibilty.

If possible contamination emissions can be controlled at the source, no risk is present regardless of the hazard or receptors.

The conclusions presented should not be considered to result from a complete survey of all of the literature available on this topic but an examination of accessible information found through the sources listed in **section 4.1**.

The conclusions presented are general in nature and cannot replace a site-specific, contaminant-specific risk assessment.

## 6.2 Evaluation of Gas Transport Pathways

The evaluation of gas transport pathways determined that two types of pathways were present between the source locations tested and the building living space. Indirect pathways refer to the transport of the tracer gas from the source through the garage buffer space to the living space. Direct pathways were considered to be those which did not pass through the garage space (and any possible buffering effect that it may have) as they travelled from the source to the living spaces. A direct pathway was found to exist between the elevator sump pit and upper-level living space. The direct transfer of soil gases to upper floor living spaces is thought to heavily rely upon the following factors:

- the relatively unobstructed pathway to this living space through the elevator shaft;
- the pumping effect caused by elevator movement in the shaft; and
- building stack effects, especially prevalent in the winter months.

The source placed at the pipe entrance through the garage ceiling slab in Building C resulted in significant gas transfer to ground and upper floor living spaces due to the lack of sealing around the pipe entrance. Though direct transfer between this source and the living space occurred, the source was not placed at a primary entry point and represents the transfer of gas that would occur after the concentration-reducing effects of the garage buffering layer had been encountered.

It is hypothesized that the transport of soil gases through these direct routes can be reduced or eliminated by incorporating the following features into building design and/or operation:

- sealing sump pits from interior space and venting them to the building exterior;
- installing and maintaining liquid traps in the piping that connects the sump pit to the elevator shaft; and
- sealing holes in the structural slab between the garage and the living space.

Transport to building living spaces along indirect pathways (i.e. through the garage space) was also potentially significant. It is theorized that the amount of gas transport occurring through indirect routes can be reduced by sealing leakage paths from the garage to the living space and designing and/or operating basement ventilation such that the building basement will act as an effective buffer zone between garage gases and air in the living spaces. The validity of this hypothesis was reinforced by the PFT tracer gas results from Building B which showed that the garage can act as an effective buffer zone. The effectiveness of this buffer zone was attributed to the Building B central air ventilation system and lack of leakage paths. In general, buffering effects can be increased by changing building and garage pressures to counteract stack effects and by increasing the air change rates to remove gases from the garage space.

## 6.3 Effectiveness of Ventilation

In all buildings, testing was conducted under two ventilation scenarios: normal operation, and the deactivation of all ventilation systems including make-up air, garage exhaust and central exhaust (Building B only). The primary purpose of the ventilation system is to change the air in the garage to remove the CO gas created by vehicle operation. Garage ventilation systems are also designed to reduce the pressure in the garage area so that garage gases are not forced upwards towards living areas. In many buildings, the garage ventilation system is not run on a full time basis. Systems such as timers and CO controls are used to activate the systems. This was true of all of the buildings included in this study. Therefore, normal operation testing did not necessarily mean that garage ventilation systems were in operation for the test period. Testing conducted with full-time operation of all building ventilation systems would be required to fully evaluate the effectiveness of ventilation systems in reducing the concentrations of garage gases found in the living spaces.

Building B, which had a central suite exhaust ventilation system, was the only building whose ventilation system effectively reduced the concentrations of tracer gases detected in building living spaces during normal operation.

## 6.4 Single Unit Homes

Data from an unpublished CMHC research study concerning the presence of radon in residential single family homes were compared to the results of gas transfer in high-rise apartment buildings found in this study. The unpublished study provides data on radon gas concentrations measured at holes drilled in the walls and floors of single family residential basements and in ambient basement air. It should be noted that the reduction in radon gas concentrations at the source location due to the opening of the holes is unknown, and no information concerning the transport of radon gas to upper level living spaces was available. This data is presented in **Appendix 7**.

In general, the data show a two-order-of magnitude reduction in concentration between the subsurface soil and the ambient air in the basement. Reductions of one and three orders of magnitude were also detected.

The present study (concerning high-rise residential buildings) found that tracer gas concentrations were reduced by three to eight orders of magnitude between emission sources at garage locations and building living spaces. This is only a marginal and inconsistent improvement over the low-rise performance.

# 7.0 CONCLUSIONS

Based on the literature search conducted concerning the risk of fugitive dust to residents of high-rise apartment buildings, it is concluded that the risk to high-rise apartment dwellers from contaminated dust is less than the risk to dwellers in single-unit homes. Emissions of dust can be reduced or eliminated at the contaminant source. Furthermore, the number of exposure pathways are reduced by the building envelope as well as by the limited on-site outdoor activities available at a high-rise building area.

Tracer gases can be transported through the high-rise apartment buildings by means of direct or indirect pathways. Indirect pathways pass through the parking garage area and the concentrations of tracer gases are buffered by dilution in this area. Direct pathways do not travel through the general garage space. A direct pathway was found to exist between the elevator sump pit and the upper level living space. Concentrations of tracer gases in building living spaces were found to be highest due to direct transport pathways.

In the winter, when stack forces are present, the concentrations of tracer gases were generally reduced by 3 to 5 orders of magnitude between the emission sources and most living spaces. The dominant transfer paths were found to be between the elevator sump pit and the top floor living spaces. In Building C, a highly significant indirect pathway was also found between a pipe entrance through the garage ceiling slab and the ground floor living space. Normalized concentrations as high as three to six times the fully mixed scenario were detected in these areas.

In summer, when stack forces are reduced or eliminated, dominant gas transfer paths were still observed between the elevator sump pit and the living spaces on the top floor of the building. Normalized concentrations slightly higher than the fully mixed scenario were detected from this source in the upper floor living space in Building C. The transfer pathway from the elevator sump pit to middle and ground floor living spaces, however, was less significant, and reductions in tracer gas concentrations of 5 to 6 orders of magnitude were generally found.

Building ventilation can affect the concentrations of tracer gas detected in the living spaces. The magnitude of the change due to ventilation-effects depends on the quality of the ventilation system and the age of the building and type of construction.

The study has determined that gas transfer pathways are present to varying degrees in the high-rise buildings researched and that these pathways are not just stack-induced, seasonal phenomena. To manage the risk associated with gas transfer, gas pathways into and through the building should be restricted.

## REFERENCES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