RESEARCH REPORT

VENTILATION SYSTEMS FOR MULTI-UNIT RESIDENTIAL BUILDING: PERFORMANCE REQUIREMENTS AND ALTERNATIVE APPROACHES

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Ventilation Systems for Multi-unit Residential Buildings - Performance Requirements and Alternative Approaches

Prepared For Canada Mortgage and Housing Corporation

Submitted by:

THE SHELTAIR GROUP
Resource Consultants Inc.

Craig Edwards, Innes Hood
The Sheltair Group Resource Consultants Inc.
#2 - 3661 West 4th Avenue
Vancouver, BC V6R 1P2

In Association with:

Mario Kani - Allen Kani and Associates
Leslie Jones - Leslie Jones & Associates
Rob Dumont - Saskatchewan Research Council

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Abstract

The goal of this project is to assist the Canada Mortgage and Housing Corporation (CMHC) in developing performance requirements and alternative approaches for innovative ventilation systems that overcome problems with conventional ventilation systems in multi-unit apartment buildings.

A review of conventional ventilation systems reveals that current designs for ventilation systems in MURBs do not work well for ensuring adequate indoor air quality. They suffer from a litany of complaints from occupants and building operators and owners about noisy systems, ineffective supply of ventilation air and removal of contaminants, and high-energy consumption

To characterise improved ventilation system performance, practical performance parameters and targets were developed. Based on an evaluation of ventilation needs for residents of multi-unit residential apartments in Canada, it is recommended that ventilation rates from the current ASHRAE Standard 62-01 be used as a basis for performance, with those rates provided fully by mechanical systems rather than relying on infiltration for part or all of ventilation supply rates.

Four alternative ventilation systems that better meet these performance targets were developed and evaluated in terms of capital cost, energy use, and operating costs. The four systems[1] are:

1. Passive inlet vents with suite based mechanical exhaust,
2. Balanced individual suite HRV units,
3. Balanced floor by floor system with heat recovery,
4. Balanced central system with heat recovery.

Based on analysis of these systems, the following observations can be made:

- System 1 provides some improvement in performance over conventional systems for a marginal cost of approximately $700 per suite.
- Systems 2 through 4 provide substantially improved performance in most or all areas at a marginal cost of between $1300 and $2300 per suite.
- Advanced ventilation systems with HRV's can exhibit more than a ten-fold reduction in operating cost over conventional ventilation systems and a five-fold reduction over similar ventilation systems without heat recovery.
- Energy cost savings of as much as $130 per suite per year are possible from advanced systems with heat recovery in new buildings.

[1] It is important to note that these alternative systems may not necessarily meet current building codes.

Executive Summary

Introduction

New multi-unit residential buildings (MURBs) are being constructed with increased envelope air tightness due to durability and energy concerns. At the same time the research community is becoming more knowledgeable about indoor air quality problems and occupants are demanding improved comfort levels. It is obvious that conventional ventilation systems in MURBs are not performing adequately to meet current demands.

The goals of this project are to assist the Canada Mortgage and Housing Corporation (CMHC) in defining ventilation rates and performance targets for multi-unit residential ventilation systems, and developing concepts and specifications for innovative, yet practical, ventilation systems appropriate for new multi-family residential apartment buildings. Specifically, this work attempts to:

1) Identify problems and issues with conventional ventilation systems that must be addressed by alternative ventilation strategies.
2) Review existing ventilation standards and develop recommendations for and a method of calculating ventilation rates for individual apartments.
3) Develop performance parameters to evaluate the performance of alternative ventilation systems.
4) Develop recommendations and specifications for improved practical ventilation strategies for individual apartments, and compare the cost and performance of these improved systems against conventional systems.

Problems and Issues with Conventional Ventilation Systems

Current designs for ventilation systems in MURBs do not work well for ensuring adequate indoor air quality. They suffer from a litany of complaints from occupants and building operators and owners about noisy systems, ineffective supply of ventilation air and removal of contaminants, and high energy consumption.

Recommendations for Ventilation Rates

An evaluation of ventilation needs for multi-unit residential apartment buildings in Canada was completed. Based on a review of the literature, it was found that ventilation rates required by relevant standards and codes vary significantly, as well as the portion of ventilation expected to be provided by infiltration. It also shows that ventilation rates required to dilute pollutants can be high. In the context of balancing the requirements to dilute contaminants, reduce capital and operating costs and avoid low RH levels, ventilation rates in the range of 7.5 L/s per person is recommended. The ASHRAE 62-01 Ventilation Rate Procedure provides the above recommended ventilation rate if the ventilation rates are provided by mechanical systems rather than relying on infiltration through exterior envelopes as assumed in the Standard.

Performance Parameters to Evaluate Alternative Ventilation Systems

To characterise ventilation performance, the following parameters and targets are proposed. This list is an abridged summary of a more detailed list of parameters, highlighting areas where specific targets were established.

Performance Parameter	Performance Target
Ventilation Performance	Continuous ventilation rate of 100% outdoor air: One bedroom apartments – 15 L/s Two bedroom apartments – 22.5 L/s Three bedroom apartments – 30 L/s Ventilation effectiveness of 1.0 or greater.
Capital and Operating Costs	Nominal increase in capital cost over conventional systems. 10 to 20% reduction in ventilation energy consumed.
Maintenance	All equipment requiring maintenance located in easily accessible locations.
Fire/Smoke Control	Minimise the need for fire dampers required for vertical ducts through floor to floor separations.
Noise Issues	0.6 sone limit on local intermittent use fans.
Comfort	No cold drafts from air supply.
System Issues	Simple to use controls. Simple to maintain. Less than 10 Pa depressurisation of suites
Owner/Designer Construction Issues	Ventilation system should not take up any more floor area than conventional systems.

Alternative Ventilation Strategies

Four alternative ventilation systems were developed to meet performance parameters that overcome the main problems associated with conventional ventilation systems in multi-unit residential buildings. The four systems and their main benefits and drawback are summarised below:

System 1 - Passive Vents with Suite Based Mechanical Exhaust

Benefits	• Least cost system, with improved supply of outdoor ventilation air over conventional systems. • Low maintenance. • Least change from current design and construction method.
Drawbacks	• Ventilation performance affected by wind effects. • No tempering of air supply may result in comfort issues in colder climates. • Requires compartmentalisation of suites to work effectively.

Application	• Best used in condominiums or rental suites in temperate locations such as Vancouver, BC.

System 2 - Balanced Individual Suite HRV Units

Benefits	• Excellent ventilation performance when combined with airtight suite design, least affected by wind and stack effects. • Reduced space requirements for vertical corridor ventilation risers.
Drawbacks	• Most expensive initial capital cost. • More fans and HRV units therefore greater maintenance. • Operation and training of occupants required. • Interior space required. • Many external vents required.
Application	• Best used in condominiums where each suite is responsibility for maintenance of their own unit. • Could be used in rental housing if HRV units are located adjacent to hallways with access panels for maintenance.

System 3 - Balanced Floor By Floor System With Heat Recovery

Benefits	• Good ventilation performance with limited negative stack effects, when combined with airtight suite design. • Centralised maintenance and control at each floor level.
Drawbacks	• Ventilation performance affected by wind effects. • Space requirement on each floor level for equipment and overhead ducts in hallways.
Application	• Best used in rental applications where centralised control and maintenance is desired. • Could also be used in individual condo applications.

System 4 - Balanced Central System with Heat Recovery

Benefits	• Good ventilation performance when using constant flow controllers at each floor level to limit negative stack effects, combined with airtight suite design. • Lower maintenance. • Centralised maintenance and control.
Drawbacks	• Ventilation performance affected by wind effects. Central systems do not allow for compartmentalisation. • Space requirement for risers and overhead ducts in hallways. • System balancing is difficult and costly.
Application	• Best used in rental applications where central control and maintenance is desired. • Could also be used in individual condo applications.

Based on analysis of these systems, the following observations can be made:

- System 1 provides some improvement in performance over conventional systems for a marginal cost of approximately $700 per suite.
- Systems 2 through 4 provide substantially improved performance in all or most areas at a marginal cost of between $1300 and $2300 per suite.
- Advanced ventilation systems with HRV's can exhibit more than a ten-fold reduction in operating cost over conventional ventilation systems and a five-fold reduction over similar ventilation systems without heat recovery.
- Energy cost savings of as much as $130 per suite per year are possible from advanced systems with heat recovery in new buildings.

Conclusions and Recommendations

Based on the results of this analysis, the following recommendations for future research are proposed:

Development and Commercialisation of Equipment

1. The following equipment is not readily available and requires further development and commercialisation:
    - A simple packaged apartment ventilation unit designed specifically in terms of flows, durability, power consumption and reliability.
    - Low cost sound traps to reduce noise transfer through ducts between suites.
    - Low cost passive inlet vents, potentially with air tempering capabilities.
    - Pressure-flow control devices to maintain constant flow rates under with variable stack and wind pressures.
    - Low temperature, low flow in duct electric heaters.
    - Low flow low power fans.

Collection of Field Data

2. More field data is required on the performance of both innovative and conventional systems such as air change rates, relative humidity values, ventilation effectiveness, and TVOC levels through all weather conditions.

Cost Information

3. Further research is required to understand the cost implications of the following aspects of alternative ventilation systems:
    - Cost or savings associated with space requirements for equipment and risers.
    - Cost of air sealing required for systems to work effectively.
    - Maintenance costs for all systems.
    - The cost of variable flow systems that can both supply continuous ventilation and supply increasing flowrates on an intermittent basis.

Modelling

4. The focus of this analysis has been on the performance of the ventilation system during the heating season. However, thermal comfort during summer months is a growing issue. Understanding the performance of the alternative ventilation strategies during warm periods is necessary to avoid overheating of apartments. Overheating of corridors is of particular concern.

5. Evaluate one other promising system that was selected for its potential but not evaluated in this study - passive suite intake and mechanical central exhaust, possibly utilising a passive HRV for heat recovery.

Specifications and Standards

6. Develop air sealing recommendations and specifications for exterior walls and interior partitions, including suite doors, to enable systems to work effectively.

Demonstration Projects

7. Construct all four alternative ventilation systems in real buildings and evaluate their as-built performance according to the performance parameters developed in this study.

8. Complete an evaluation of MURBs with alternative ventilation systems to measure performance and identify lessons learned.

Other

9. Further study is required to set stack and wind pressure targets for designers to work with in specifying equipment.

10. Further study is required to set a target for operating hours between maintenance and replacement intervals.

Résumé

Introduction

Les nouveaux collectifs d'habitation sont construits avec une enveloppe de plus en plus étanche pour des considérations de durabilité et d'énergie. Aussi, les chercheurs sont de mieux en mieux informés des problèmes de qualité de l'air intérieur et les occupants demandent de meilleurs niveaux de confort. Il est évident que les installations de ventilation classiques dans les collectifs d'habitation n'offrent pas un rendement adéquat pour satisfaire les demandes actuelles.

Le but de la présente étude est d'aider la Société canadienne d'hypothèques et de logement (SCHL) à définir des taux de ventilation et des cibles de performance pour les installations de ventilation dans les collectifs d'habitation. Elle vise également à élaborer des concepts et des spécifications relatifs à des installations de ventilation innovatrices et pratiques, appropriées pour les nouveaux collectifs d'habitation. Plus particulièrement, le travail vise à :

1) cerner les problèmes et les questions liés aux installations de ventilation classiques devant être traités par les nouvelles stratégies en matière de ventilation;
2) examiner les normes existantes en matière de ventilation et à élaborer des recommandations et une méthode de calcul en ce qui a trait aux taux de ventilation des logements;
3) élaborer des paramètres de performance pour évaluer les nouvelles installations de ventilation;
4) formuler des recommandations et des spécifications portant sur des stratégies de ventilation pratiques et améliorées dans les logements et comparer le coût et le rendement des installations améliorées à ceux des installations classiques.

Problèmes liés aux installations de ventilation classiques

La conception actuelle des installations de ventilation dans les collectifs n'est pas adéquate pour garantir une qualité de l'air intérieur suffisante. Elle suscite de nombreuses plaintes de la part des occupants, des responsables du fonctionnement des immeubles et des propriétaires au sujet du bruit provenant des installations, de l'inefficacité de l'alimentation en air, de l'élimination des polluants et de la consommation élevée d'énergie.

Recommandations relatives aux taux de ventilation

Une évaluation des besoins de ventilation dans les collectifs d'habitation a été réalisée au Canada. La recherche documentaire a révélé que les taux de ventilation exigés par les normes et les codes pertinents ainsi que la part de ventilation devant être fournie par infiltration varient de façon significative. Elle a également révélé que les taux de ventilation exigés pour diluer les polluants peuvent être élevés. Afin de trouver un équilibre entre les exigences en matière de dilution des contaminants et la réduction des

coûts d'investissement et de fonctionnement, et d'éviter de faibles niveaux d'humidité relative, on recommande un taux de ventilation d'environ 7,5 L/s par personne. La méthode du taux de ventilation prévu dans la norme 62-01 de l'ASHRAE donne le taux mentionné ci-dessus si les taux de ventilation sont fournis par des installations mécaniques plutôt que par l'infiltration à travers l'enveloppe comme il est supposé dans la norme.

Paramètres de performance pour évaluer les nouvelles installations de ventilation

Les cibles et les paramètres qui suivent sont proposés pour caractériser la performance en matière de ventilation. La liste représente une version abrégée d'une liste de paramètres plus détaillée qui souligne les aires dans lesquelles des cibles précises ont été établies.

Paramètre de performance	Cibles
Performance en matière de ventilation	Taux de renouvellement d'air continu de 100 % d'air extérieur : Logements d'une chambre – 15 L/s Logements de deux chambres – 22,5 L/s Logements de trois chambres – 30 L/s Efficacité de ventilation de 1 ou plus.
Coûts d'immobilisation et d'exploitation	Hausse minimale du coût d'investissement par rapport aux installations classiques. Réduction de 10 à 20 % de l'énergie consommée.
Entretien	Accès facile au matériel qui nécessite de l'entretien.
Maîtrise du feu ou de la fumée	Réduction du besoin de registres coupe-feu nécessaires pour les conduits verticaux dans les séparations d'étage.
Bruit	Limite de 0,6 sone pour les ventilateurs locaux à utilisation intermittente.
Confort	Absence de courant d'air froid provenant de l'alimentation en air.
Enjeux relatifs aux installations	Commandes faciles à utiliser. Entretien facile. Dépressurisation des logements de moins de 10 Pa.
Propriétaire ou concepteur - Enjeux relatifs à la construction	L'installation de ventilation ne doit pas occuper une surface de plancher plus grande que l'installation classique.

Nouvelles stratégies en matière de ventilation

Quatre nouvelles installations de ventilation ont été conçues pour satisfaire aux paramètres de performance devant régler les principales déficiences des installations classiques dans les collectifs d'habitation. Voici un résumé des quatre installations et de leurs principaux avantages et inconvénients :

Installation 1 – Prises d'air passives jumelées à une ventilation mécanique dans chaque logement

Avantages	• Installation la moins coûteuse, offrant une meilleure alimentation en air frais que les installations classiques. • Nécessite peu d'entretien. • Semblable à la méthode de conception et de construction actuelle.
Inconvénients	• Les effets du vent ont une incidence sur la performance. • Une alimentation en air frais non conditionné peu entraîner des problèmes de confort en région froide. • Il est nécessaire de compartimenter les logements pour obtenir une performance élevée.
Cas d'utilisation	• Convient aux logements en copropriété ou les immeubles locatifs situés dans des endroits tempérés, tels que Vancouver en Colombie-Britannique.

Installation 2 – Ventilateurs récupérateurs de chaleur (VRC) équilibrés dans les appartements individuels

Avantages	• Offre un excellent rendement lorsque le logement est étanche à l'air; et est la moins touchée par les effets du vent et par l'effet de tirage. • L'espace nécessaire pour les colonnes montantes de ventilation dans les corridors est moindre.
Inconvénients	• Coût d'investissement initial le plus élevé. • Nombre de ventilateurs et de VRC plus grand, ce qui nécessite plus d'entretien. • Formation et participation des occupants nécessaires. • Espace intérieur nécessaire. • De nombreux tuyaux de ventilation extérieurs sont nécessaires.
Cas d'utilisation	• Convient aux immeubles en copropriété dont l'entretien de chaque logement est la responsabilité de l'occupant. • Peut être utilisée dans les immeubles locatifs si les VRC sont adjacents aux corridors avec des trappes d'accès pour en permettre l'entretien.

Installation 3 – Installation équilibrée à chaque étage avec récupération de chaleur

Avantages	• Offre un bon rendement et un effet de tirage négatif restreint lorsque le logement est étanche à l'air. • Système de commande et d'entretien central à chaque étage.
Inconvénients	• Les effets du vent ont une incidence sur la performance. • De l'espace est nécessaire à chaque étage pour le matériel et les conduits au plafond des corridors.
Cas d'utilisation	• Convient bien dans les immeubles locatifs où un système central de commande et d'entretien est souhaité. • Peut être également utilisée dans les immeubles en copropriété.

Installation 4 – Installation centrale équilibrée avec récupération de chaleur

Avantages	• Offre un bon rendement lorsque des régulateurs de débit constants sont utilisés à chaque étage pour limiter l'effet de tirage négatif et que le logement est étanche à l'air. • Nécessite peu d'entretien. • Système de commande et d'entretien central.
Inconvénients	• Les effets du vent ont une incidence sur la performance. Les installations centrales ne permettent pas la compartimentation. • Il faut de l'espace additionnel pour les colonnes montantes et les conduits au plafond des corridors. • L'équilibrage de l'installation est difficile et coûteux.
Cas d'utilisation	• Convient aux immeubles locatifs où un système de commande et d'entretien central est souhaité. • Peut être également utilisée dans les immeubles en copropriété.

Après analyse de ces installations, on note les résultats suivants :

- l'installation 1 offre une meilleure performance que les installations classiques avec un coût supplémentaire d'environ 700 $ par logement;
- les installations 2, 3 et 4 présentent une performance grandement améliorée dans toutes ou la plupart des aires à un coût additionnel allant de 1 300 $ à 2 300 $ par logement;
- grâce aux installations de ventilation évoluées dotées de VRC, le coût d'exploitation peut être réduit par un facteur de 10 comparativement aux installations classiques et par un facteur de 5 comparativement aux installations semblables sans récupération de chaleur;
- dans les collectifs d'habitation neufs, il est possible d'épargner jusqu'à 130 $ par appartement par année sur les frais énergétiques grâce à des installations évoluées avec récupération de chaleur.

Conclusions et recommandations

Considérant les résultats de l'analyse, des recommandations de recherches futures sont proposées.

Élaboration et commercialisation du matériel

1. Le matériel qui suit ne se trouve pas facilement et nécessite un développement et une commercialisation plus poussés :
    - un simple équipement autonome de ventilation pour logement conçu spécifiquement en fonction des critères de débit, de durabilité, de consommation énergétique et de fiabilité;
    - des silencieux abordables pour réduire la transmission du bruit entre les appartements par l'intermédiaire des conduits;
    - des prises d'air passives à coût abordables, présentant peut-être des possibilités de conditionnement de l'air;
    - des dispositifs de régulation de la pression et du débit pour maintenir un débit constant suivant des pressions variables dus au vent et à l'effet de tirage;
    - des serpentins électriques à faible température de fonctionnement et à faible débit à installer dans les conduits;
    - des ventilateurs à débit réduit et à faible consommation.

Collecte de données sur le terrain

2. Il est nécessaire de recueillir sur le terrain plus de données sur le rendement des installations classiques et innovatrices, comme les taux de ventilation, les valeurs d'humidité relative, l'efficacité de la ventilation et les niveaux de composés organiques volatils totaux (CVOT) et ce, dans toutes les conditions climatiques.

Information sur le coût

3. Il faudra mener d'autres recherches pour mieux comprendre les aspects relatifs aux coût des nouvelles installations :
    - les coûts ou les économies découlant des exigences d'espace relatives au matériel et aux colonnes montantes;
    - le coût lié à l'étanchéité à l'air nécessaire pour que les installations fonctionnent de manière efficace;
    - le coût d'entretien de toutes les installations;
    - le coût des installations à débit variable qui pouvant fournir une ventilation continue ainsi que des débits plus élevés sur une base intermittente.

Modélisation

4. On a mis l'accent sur la performance de l'installation de ventilation durant la saison de chauffage. Le confort thermal durant les mois d'été est toutefois une préoccupation croissante. Il est nécessaire de comprendre le rendement des nouvelles installations durant les périodes chaudes afin d'éviter de surchauffer les appartements. La surchauffe des corridors constitue une préoccupation importante.

5. Une autre installation prometteuse, choisie pour son potentiel, mais qui n'a pas été évaluée dans le cadre de la présente étude, doit être évaluée : une prise d'air passive et une ventilation mécanique centrale, peut-être jumelée à un VRC passif pour la récupération de la chaleur.

Spécifications et normes

6. Des recommandations et des spécifications en matière d'étanchéité à l'air des murs extérieurs et des cloisons intérieures, y compris les portes d'appartement, doivent être élaborées pour permettre aux installations de fonctionner efficacement.

Initiatives de démonstration

7. Les quatre nouvelles installations de ventilation doivent être réalisées dans de bâtiments réels et leur performance évaluée en fonction des paramètres élaborés dans la présente étude.

8. La performance globale des collectifs d'habitation dotés de nouvelles installations de ventilation doit être évaluée et des leçons tirées.

Autre

9. Il est nécessaire de mener des travaux pour établir des cibles relatives à la pression du vent et de l'effet de tirage, lesquelles serviront de guide aux concepteurs pour l'établissement des spécifications visant le matériel.

Il est également nécessaire de mener une étude pour établir une cible d'heures de fonctionnement entre les intervalles d'entretien et de remplacement.

CMHC SCHL

National Office
700 Montreal Road
Ottawa ON K1A 0P7
Telephone: (613) 748-2000

Bureau national
700 chemin de Montréal
Ottawa ON K1A 0P7
Téléphone : (613) 748-2000

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1 Introduction

Multi-unit residential buildings (MURBs) are being constructed with increased envelope air tightness due to durability and energy concerns. At the same time the research community is becoming more knowledgeable about indoor air quality problems and occupants are demanding improved comfort levels. It is obvious that conventional ventilation systems in MURBs are not performing adequately to meet current demands.

The goals of this project are to assist the Canada Mortgage and Housing Corporation (CMHC) in defining ventilation rates required for individual apartment suites, and developing concepts and specifications for innovative yet practical ventilation systems that are more appropriate for new multi-family residential apartment buildings.

1.1 Project Objectives

The following are the objectives of this project:

1) Identify problems and issues with conventional ventilation systems that must be addressed by alternative ventilation strategies.
2) Review existing ventilation standards, and develop recommendations for ventilation rates and a method for calculating ventilation rates for individual apartments.
3) Develop performance parameters to evaluate the performance of alternative ventilation systems.
4) Develop recommendations and specifications for improved practical ventilation strategies for individual apartments and compare the cost and performance of these improved systems against conventional systems.

1.2 Scope

The scope of this project is limited to:

- Multi-family buildings of any size with suite entry from common interior corridors.
- New buildings with building envelope construction equal to or better than required by current building codes.

1.3 Background

Research by CMHC and others has shown that conventional ventilation systems in MURBs are deficient in providing controlled supplies of fresh air to individual apartments. They also contribute to excessive use and cost of energy to condition ventilation air, and energy losses associated with infiltration airflow.

The impacts of these deficiencies have been increasing due to a number of recent changes in occupant expectations and building construction practices. Durability concerns are driving increased air tightness of building envelopes to reduce the potential for water penetration. Energy costs and environmental impacts are also driving the push for tighter building envelopes. At the same time as accidental ventilation has been decreasing, the quantity of contaminants released into dwellings has been increasing from construction materials, furniture and items used indoors. Occupants are also starting to become more aware of these indoor air quality issues.

It is clear that conventional systems - i.e. kitchen and bathroom exhaust fans with central hall pressurisation systems - fail in principle and practice. Standards, regulations, and design guidance for ventilation rates and the design and installation of ventilation systems in MURBs are also lacking. Reasons for this failure include:

- building air leakage, stack effect, wind, and inter-floor leakage which results in lower and windward suites receiving excessive infiltration and other units receiving second-hand air.
- hallway supply is rarely balanced floor-to-floor, never matches exhaust rates, varies considerably due to changing stack pressures, and is often shut down due to breakdown or scheduling for energy savings.
- corridor door undercut leakage is typically inadequate, often defeated by occupant weather-stripping to limit noise and odour transfer.
- exhaust fans are rarely utilised due to noise and lack of apparent performance.
- the quality of exhaust fans and ducting typically results in early failure, poor performance, and inadequate maintenance.

Poor performance of these systems then leads to:

- Poor air quality, cross-contamination among suites of odour, smoke, germs, and other contaminants, and excessive dryness in some cases of excess air change.
- Mould and deterioration from condensation at windows and at thermal bridges such as floor edges when relative humidity is not controlled.
- Construction deterioration due to exfiltration air in wall assemblies.
- High operating costs for heating, cooling, and ventilation energy.
- Supply air contaminants due to ambient conditions and improper supply air location such as garages, cooling towers, waste storage, adjacent operations, and direct-fired heaters.
- Inadequate ability to supply variable ventilation demands depending on occupant activities.
- Inadequate ventilation or overheating resulting in occupants opening windows, resulting in discomfort, wasted energy, and noise transfer.

It is clear that new approaches to the design of ventilation systems for MURBs are required, and these approaches must be integrated with other building systems as part of a shift toward healthy housing.

1.4 Report Outline

The remainder of the report is structured as follows:

- Performance problems and issues with conventional ventilation systems are discussed in Chapter 2.
- A review of existing ventilation standards is presented in Chapter 3.
- Performance parameters to evaluate the performance of alternative ventilation systems are presented in Chapter 4.

- Chapter 5 identifies potential alternative ventilation strategies and quantifies the energy and economics of each.
- Chapter 6 provides report conclusions.
- Chapter 7 provides a set of recommendations for future work.

2 Experience with Current MURB Ventilation Systems

2.1 Literature Review

A literature review was conducted to identify problems and issues that must be addressed by alternative ventilation systems. The most relevant research is described below.

2.1.1 Ventilation System Complaints

The most comprehensive cataloguing of problems relating to ventilation systems in MURBs in Canada is probably the report by Jones (1991). In it a review of literature and a nation wide survey of 260 high rise multi-family buildings was carried out to identify typical practice, and problems with HVAC systems.

The majority of people interviewed were developers, owners, managers, and operators. It was found that 95% of buildings surveyed had central corridor supply systems supplying make up air to individual suites though door undercuts and cracks. Ventilation system equipment and performance related complaints were found to be predominant over issues related to other HVAC systems such as heating, air conditioning, DHW, and garage heating and ventilation systems. Ventilation related issues that were most often found (in order of the greatest number of complaints identified in the report) were:

2.1.1.1 Noise

- Small ceiling exhaust fans that are so noisy that they simply do not get used.
- Noise from central ventilation systems in apartments located close to central ventilating equipment, and in corridors.
- Air noise (whistling) created by makeup airflow though corridor access doors.
- The transmission of noise from corridors through access door undercuts required for makeup airflow.
- Noise transfer though central ventilation system ductwork.

2.1.1.2 Poor Ventilation System Performance

- Movement of odours, particularly the transfer of cooking odours into corridors, was the most common ventilation performance complaint.
- Transfer of tobacco smoke from public corridors and lobbies.
- Complete lack of ventilation when central systems are scheduled off.
- Condensation on windows due to lack of ventilation or avoided use of exhaust fans during cooking and bathing.
- Corridors being too cold in winter and too hot and "stuffy" in the summer.
- Cold air infiltration through corridor duct systems as a result of operators shutting off corridor ventilation systems to reduce energy consumption, to minimise evening noise, or because the system is inadequate to temper air to comfortable levels in cold weather.

- Duct leakage from unsealed joints reducing the ability of systems to deliver air to where it is needed - resulting from generally poor standards of duct construction in the residential industry.
- Undersized ventilation systems, inadequate exhaust performance, and/or lack of proper balancing creating localised air quality problems.

2.1.1.3 Envelope Leakage

(Included as ventilation related issues because conventional ventilation strategies rely in part on air leakage through the building envelope)

- Building envelope deterioration resulting from air leakage related rain penetration or condensation.
- Adverse effects on heating performance (some areas too hot and others too cold).
- Reversal of designed ventilation airflow patterns resulting from stack and wind induced airflow that would not occur without envelope leakage.
- Significant infiltration through ventilation system outdoor air dampers - they are often found to be non-functional, and even when fully functional they do not provide a tight seal.

2.1.1.4 Other Problems

- Lack of reliability of equipment.
- High energy costs - greater energy consumption on a floor area basis than single family or townhouse buildings.
- Condensation on windows.
- High capital cost of the make-up air system.
- Loss of fire integrity - Central duct systems are considered a potential compromise of fire integrity because they provide a potential source for the movement of fire and smoke through the building. Thermally activated fire dampers are usually required by code to block this pathway. However fire and smoke integrity problems identified in the survey include missing fire dampers, dampers installed upside down or out of the plane of fire separation, fire dampers that are not designed to stop smoke transfer, and lack of appropriate packing between the ductwork and structure creating an alternative fire/smoke pathway.
- Windows opened to control winter overheating.
- Lint collection in dryer ducts leading to reduced dryer efficiency (and building envelope damage if ducts leak into the envelope)

2.1.2 Ventilation Effectiveness

In a survey of designers of mechanical ventilation systems for mid and high rise residential buildings in Canada performed by Wray et al (1998), it was found that corridor supply air systems are generally designed to pressurise the corridors relative to suites with the intent of limiting the migration of contaminants between suites. Most designers do not intend the corridor air system to act as a ventilation system for apartments. However, most property owners, managers, and occupants tend to think of the corridor air systems as a ventilation system for individual suites.

When designing the corridor supply system, designers typically do not specify and have little or no information regarding the actual airtightness of the combined corridor wall and suite access door assemblies or of the airtightness of the building envelope or other components effecting corridor pressurisation. Furthermore, they seldom take into account the effects of stack- and wind-induced pressure differences. They do typically use safety factors of 25 to 125 Pa to take some of these uncertainties into account.

Rarely are corridor ventilation systems designed specifically to provide ventilation for the suites. However, in the absence of other driving forces and when in-suite exhaust equipment is not operating, the corridor supply air system will also pressurise the suites relative to outdoors and will provide some suite ventilation, because the suites are not completely isolated from the corridor or outdoors. Consequently, the pressure in the corridor relative to the suites is unknown, the amount of air leaking from the corridor into the suites is unknown, and suite ventilation occurs more through accident than design.

In the same study Wray et al. (1998) measured the flow-rates of corridor ventilation systems in 10 mid and high rise apartment buildings across Canada and compared the results to design flow-rates and minimum outdoor air requirements. The ten buildings ranged in height from 6 to 32 stories and were all built between 1990 and 1995. The results are shown in Figure 1.

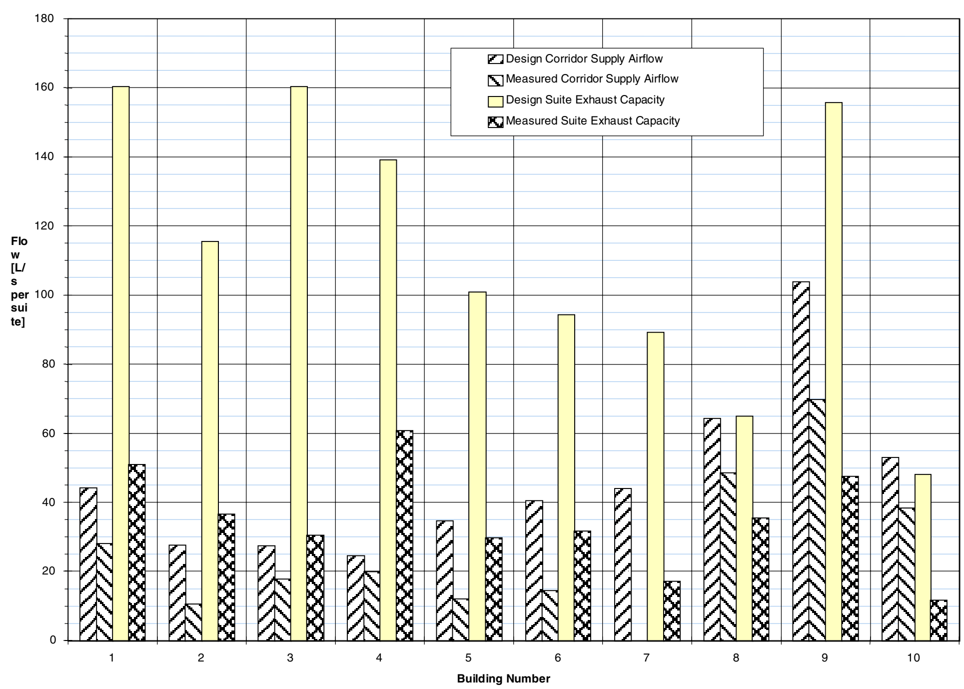


Figure 1: Design and Measured Corridor Supply Airflows and Suite Exhaust Capacities in Canadian Mid and High Rise Apartment Buildings

Wray et al. found a wide variation in the design specification of corridor supply airflows, with specified design airflows ranging from 25 to 109 L/s per suite, or 40 L/s per suite on average. This corresponds to 154 to 461% of the minimum outdoor air capacity requirements of ASHRAE Standard 62-01, with an average of 264% (minimum ventilation rates based on 7.5 L/s per person and occupancy assumption from ASHRAE 62-01). Measured corridor supply airflows were found to be significantly lower than design airflows, ranging from 34% to 81% of design flows, with an average of 59%. This corresponds to flow-rates of 53% to 310% of ASHRAE 62-01 Standard minimum outdoor air requirements, with an average of 160%.

Feustel and Diamond (1996) also measured corridor ventilation system supply airflows in a number of mid and high rise apartment buildings in the US. For one building for which sufficient data was provided to calculate airflows on a per suite basis, a 13-story apartment building in California, corridor supply airflow rates were measured at 6 to 15 L/s per suite, with an average of 10 L/s per suite.

Another study on ventilation in multi-family buildings was conducted by the New York State Energy Research and Development Authority (Shapiro-Baruch, 1993). They developed and tested a ventilation audit in 10 multi-family buildings, finding measured airflow rates to be on average 32% less than the design values. Energy use for mechanical ventilation varied widely from building to building, from less than 2% to more than 20%. They identified poorly designed and poorly operated supply air systems as the source of many indoor air quality problems.

Diamond, Feustal, and Dickerhoff (1996) performed airflow measurements and carried out airflow modelling simulations on a 13-story apartment building located in Massachusetts. They found that without the corridor air supply system operating and with no wind, suites at the lower level of the building receive adequate ventilation only on days with high indoor to outdoor temperature differences, while units on higher floors receive no outdoor air ventilation under all indoor to outdoor temperature differences. Units facing the windward side were found to be over-ventilated when the building experiences wind induced pressure effects. At the same time, leeward apartments do not receive any outdoor air because outdoor air enters suites from the corridor and exits through exhaust shafts and leakage paths in the building facade.

With the mechanical ventilation system operating, they found slightly higher rates of outdoor airflow into apartments, but similar effects of inadequate outdoor air supply to individual suites. While the corridor ventilation system is designed to provide outdoor air to suites, they found the direction of airflow between suites and the corridor to vary widely depending on location and outdoor conditions.

The conclusion that is drawn from these studies is that current designs for ventilation systems in mid and high rise apartment buildings do not work well for either ensuring adequate indoor air quality or reducing energy consumption attributable to infiltration airflow. Shutting off corridor ventilation systems at low outdoor air temperatures can save energy, but at the risk of reducing already hit and miss indoor air quality in individual suites.

2.1.3 Ventilation Effectiveness of HRV Units

The CMHC report “Field Survey of Heat Recovery Ventilation Systems" examined the ventilation effectiveness of HRV ventilation systems in 60 existing one to fifteen year old single-family homes. The authors measured apparent ventilation rates (i.e. total ventilation rates to a room from outside and from other rooms) during spring and early summer months and found average natural ventilation rates of 0.15 ACH with HRV systems turned off and 0.42 ACH with HRV systems operating as close as possible to the CAN/CSA-F326-M91 minimum ventilation capacity. Not surprisingly, the authors found that distribution and circulation is required for ventilation to individual rooms.

The authors surveyed occupant use of HRV's and found that 80% use their HRV's continuously in winter, and 20% intermittently. One of the main reasons why some occupants only used their HRV's intermittently in winter was due to air being too dry. Interestingly, on the West Coast, where indoor humidity levels are typically much higher in the winter, all surveyed occupants ran their HRV's continuously throughout the year. Further, the authors noted that occupants had trouble with the operation and maintenance of their HRV’s. Finally, it was found that ventilation systems connected to forced air heating ducts required the system fan to run to distribute the ventilation air as the HRV did not have the capacity to distribute the ventilation air.

2.1.4 Exhaust System Effectiveness

Intermittent exhaust systems such as in-suite kitchen or bathroom exhausts are usually occupant-controlled by a manual or humidistat-activated switch located within the suite. Intermittent exhaust systems tend to use small low-pressure fans to exhaust indoor air from the suites through ducts connected to outdoors. Most of these fans are typically rated at a static pressure difference of about 25 to 60 Pa. Stall pressures for some of these devices can be in the range of 30 to 50 Pa (Caneta 1992). The ducts connected to these fans often include several elbows and are long because the kitchens and washrooms are not usually located near exterior walls. As air flows through these ducts, the static pressure within the duct decreases due to friction and turbulence effects. Designers usually oversize the fans in an attempt to compensate for these pressure losses. However, designers rarely specify static pressure requirements for these systems.

Continuous exhaust systems typically have one or more central “constant volume” fans that are connected by vertical ducts to several or all of the suites within the building. Often in these systems, branch ducts and exhaust grilles are installed without balancing devices, such as dampers.

All of the suite exhaust systems are intended to provide supplemental ventilation for a suite. As a result, these exhaust systems require that makeup air (primarily outdoor air) enter the suite to replace the exhausted air. The corridor air supply systems are intended to provide some of this makeup air. Designers expect that the remainder of the makeup air will be provided by outdoor air infiltration through exterior walls.

Wray et al. (1998) measured the total exhaust capacity with all exhaust devices operating in suites of 10 mid and high rise apartment buildings across Canada, and compared the results to design exhaust capacities. Flow-rates were measured while each suite was depressurised to 20 Pa. The authors found design specifications for total suite exhaust capacities of the test suites ranged from 48 to 160 L/s per suite with an average of 113 L/s per suite. Based on the total volume of the test suites, these exhaust capacities correspond to suite air exchange rates in the range of 1.22 to 4.91 ach, with an average of 2.88 ach. Typically, the total design exhaust capacities are in the range of 120 to 400% of the total suite exhaust capacities required by ASHRAE Standard 62-01 and CSA Standard F326.

Measured exhaust capacities were always considerably lower than the design exhaust capacities. The installed capacities of suite exhaust devices were only a small fraction of the exhaust capacities specified by the designers. Measured total exhaust capacities for the test suites ranged from 19 to 54% of the design capacities with an average of 32%.

2.1.5 Air Tightness and Compartmentalisation

Phillips (1999) investigated the impact of corridor ventilation system operation on overall building energy use in five high rise multi-unit apartment buildings in Winnipeg during the heating season. They found that the increase in whole building energy use when the corridor ventilation system was operated in the five buildings ranged from 60% to 90% of the energy that would be required to condition the air flowing though the corridor ventilation system. Phillips concluded that heated air from corridor air systems was finding direct routes to the outside, bypassing most areas of the building envelope, and that only modest amounts of infiltration were being displaced through corridor pressurisation. It was also concluded that the energy used to condition the building's corridors does not offset energy used to condition suites in the building. The implication on ventilation system design is that the functionality of corridor air systems should be questioned since significant amounts of the air provided do not flow to where they are required.

Handegord (2001) investigated the influence of leakage characteristics of exterior walls, partitions, entry doors, and stair shaft and elevator doors on high rise apartment air flow patterns and pressure differences developed due to wind and building stack effects. He concluded that improvements in air tightness of these components plus elimination (or sealing off) of central air handling units would allow individual apartment or floor-by-floor ventilation systems to operate effectively.

The new approach to ventilation that he suggests is to eliminate central corridor ventilation systems, compartmentalise units, and use exhaust only systems on a unit by unit or floor by floor basis that draw in required rates of ventilation through leakage openings in the exterior envelope. The advantages of this strategy include improved ventilation control through the elimination of wind and stack effect related air movement problems, improved fire, smoke, and sound control, improved effectiveness of operable windows and natural ventilation openings, and reduced moisture condensation building envelope problems.

2.1.6 Energy Efficient Ventilation Design

Diamond, Feustel and Matson (1999) in their guide entitled "Energy Efficient Ventilation for Apartment Buildings", describe approaches for designing energy efficient ventilation systems in apartment buildings. They discuss performance and cost advantages and disadvantages of different mechanical and natural ventilation strategies in different climates (exhaust only, balanced, supply only, and natural ventilation) and provide recommendations for optimising natural and mechanical design strategies. They suggest that compartmentalisation and increasing air tightness between units and floors and within the building envelope (including sealing between units and corridors) is an essential part of all strategies in cold climates.

2.2 Summary of Literature Review

What this literature search points out is that engineers are generally designing ventilation systems in apartment buildings with common corridors to pressurise the corridors relative to suites with the intent of limiting the migration of contaminants between suites. They are not designing apartment ventilation systems to provide ventilation for indoor air quality, but are relying instead on infiltration through exterior walls and the use of operable windows for ventilation. These conventional corridor ventilation systems cannot and should not be expected to be apartment ventilation systems.

Studies measuring ventilation rates to individual suites have shown that outdoor air ventilation rates with windows closed are often inadequate. Airflow through these buildings is strongly affected by windows and stack effects, resulting in some suites that are under-ventilated and other suites that are over ventilated. Even if the suites are over-ventilated, the airflow is likely not fresh outdoor air, but rather airflow from windward suites travelling across corridors to leeward suites, or from lower level suites to upper level sites, through large internal leakage paths.

While conventional ventilation systems cost money to install, and do little to meet indoor air quality requirements, they contribute to excessive energy consumption through over ventilation and excessive infiltration and cause occupant and owner complaints about noise, poor performance, and excessive operating and maintenance costs.

3 Ventilation Rates for Multi-family Residential Buildings

Existing codes, standards, and guidelines were reviewed to identify and compare their requirements for ventilation rates when applied to typical one-, two-, and three-bedroom suites in multi-family residential buildings. Ventilation rates required to dilute residential indoor air pollutants to acceptable limits were then calculated and compared to ventilation rates required by existing codes, standards and guidelines for the same typical apartments. Finally recommendations for ventilation rates in Canadian multi-family residential suites are proposed.

3.1 Building Code and Standards Requirements

Because most ventilation rate requirements are based on either the number of occupants, floor area, or the volume of the space, these parameters had to be defined for typical one-, two-, and three-bedroom apartments. The number of occupants per suite was defined as equal to the number of bedrooms plus one, as defined by ASHRAE Standards 62-01and 62.2. The Survey of Household Energy use carried out by Statistics Canada for NRCan in 1994 found that nearly one third (32%) of all apartments in Canada are less than 55.7 m^2 (600 ft2) and nearly half (47%) are between 55.7 m^2 (600 ft2) and 92.3 m^2 (1000 ft2). Based on this information the floor area of typical apartments was selected as 55.7, 74.3, and 92.9 m^2 (600, 800, and 1000 ft^2) one-, two-, and three-bedroom apartments respectively. These assumptions are summarised in Table 1. For calculating apartment volume, a 2.43 m (8 ft) ceiling height was assumed for all apartments.

Table 1: Apartment size and occupant assumptions

Number of Bedrooms	# Persons	Floor Area
One	2	55.7 m^2 (600 ft^2)
Two	3	74.3 m^2 (800 ft^2)
Three	4	92.9 m^2 (1000 ft^2)

3.1.1 ASHRAE Standard 62-01 Ventilation Rate Procedure

ASHRAE Standard 62-01 "Ventilation for Acceptable Indoor Air Quality" requires outdoor air ventilation rates of 0.35 ach or 7.5 l/s (15 cfm), whichever is higher. This is a total ventilation rate of outdoor air including both ventilation and/or infiltration, and the Standard suggests that in residential applications this rate of ventilation is normally satisfied with infiltration and natural ventilation. For the size of typical one-, two-, and three-bedroom apartments chosen for comparison in this study, 7.5 L/s per person provides the higher ventilation rate in all cases, resulting in air change rates of 0.40 to 0.48 air changes per hour (ach).

Because the ventilation rate is based on a flow rate per person, larger floor area apartments can have lower air change rates, down to a minimum of 0.35 ach.

ASHRAE Standard 62-01 also contains requirements for either continuous or intermittent exhaust capacities for bathrooms and kitchens that do not have windows. These are requirements for exhaust rates rather than for ventilation air supply and are not additive to the requirements for ventilation air supply. Intermittent exhaust capacities required are 50 L/s for kitchens and 25 L/s for bathrooms. Continuous exhaust capacity requirements are 12L/s (25 cfm) for kitchens and 10 L/s (20 cfm) for bathrooms. These exhaust capacities provide ventilation rates of 11.0 to 5.5 L/s per person and 0.7 to 0.39 ach for the typical one to three-bedroom apartments, with the lower rates corresponding to apartments with increasing numbers of bedrooms. For larger size apartments these exhaust capacities provide lower ventilation rates on an air change per hour basis.

3.1.2 ASHRAE Standard 62.2

ASHRAE Standard 62.2, "Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings", is a draft Standard under development by ASHRAE. It is intended to define requirements that will result in acceptable indoor air quality in single-family houses and multi-family buildings of three stories or less.

The public review draft reviewed for this study, dated August 11, 2000, requires minimum whole house mechanical ventilation rates of 7.5 L/s (15 cfm) per person plus 5 L/s per 100 m^2 (1 cfm per 100 ft^2) conditioned floor area. The Standard also assumes that an additional infiltration rate (or credit) of 5 L/s per 100 m^2 (1 cfm per 100 ft^2) of conditioned floor area will contribute to the total ventilation rate. The whole house ventilation rates must be supplied with a mechanical ventilation system that can be operated either intermittently or continuously. To provide the same effective ventilation rate, systems that operate intermittently must supply more air than continuously operating systems, using a defined effective ventilation calculation method.

These requirements for mechanical ventilation plus the credit for infiltration result in ventilation rates ranging from 10.3 to 9.8 L/s per person or 0.54 to 0.62 ach for the typical one to three bedroom apartments. Because the ventilation rate is linked to floor area, larger size apartments require higher ventilation rates on a per person basis. However the ventilation rate decreases on an ach basis. For example, a one bedroom 46.5 m^2 (500ft^2) apartment requires 9.8 L/s per person or 0.62 ach. For a larger 93 m^2 (1000ft^2) one bedroom apartment the same ventilation rate calculation method results in total ventilation rates of 12.1 L/s per person or 0.39 ach.

3.1.3 Proposed Revisions to ASHRAE Standard 62.2

During the public review of ASHRAE Standard 62.2 construction industry representatives voiced concerns that in the US south-east, where humidity levels are high, there is no dehumidification equipment available that can handle the humidity loads resulting from the incremental ventilation rates required by ASHRAE Standard 62.2 over ASHRAE Standard 62-99, and that inadequate dehumidification might promote mould growth, reducing indoor air quality. As a result, ASHRAE Standard Standing Project Committee 62.2 has recommended that the mechanical ventilation requirement be reduced to 3.75 L/s (7.5 cfm) per person plus 5 L/s per 100 m^2 (1 cfm per 100 ft^2)

conditioned floor area, and allow for an infiltration rate credit of 10 L/s per 100 m^2 (2 cfm per 100 ft^2) of conditioned floor area.

These requirements for mechanical ventilation plus the credit for infiltration result in ventilation rates ranging from 7.9 to 7.2 L/s per person or 0.42 to 0.46 ach for the typical one to three-bedroom apartments. These ventilation rates are significantly lower than required by the August 2000 Draft ASHRAE Standard 62.2, and similar to the rates required by ASHRAE Standard 62-99.

With the proposed revisions, the ventilation rate is even more strongly linked to floor area. Larger apartment sizes require higher ventilation rates on a per person basis, but lower ventilation rates on an ach basis. Using the same example of a one bedroom apartment of two different sizes, a one bedroom 46.5 m^2 (500ft^2) apartment requires 7.2 L/s per person or 0.46 ach, while a larger 93 m^2 (1000ft^2) one bedroom apartment requires total ventilation rates of 10.7 L/s per person or 0.34 ach. For both size apartments these ventilation rates are significantly lower than required by the non-revised standard, and have a greater portion of ventilation provided by infiltration. They are also slightly lower than the requirements of ASHRAE Standard 62-01 for both the small and large size example one bedroom apartments.

The minimum ventilation rates suggested in the August 2000 Public Review Draft of ASHRAE Standard 62.2 are significantly higher than required in the original ASHRAE Standard. The argument for decreasing the requirement for these ventilation rates based on humidity concerns is not really relevant to Canadian climates. However in Canadian climates we should have the same concern over increased ventilation rate requirements based on concerns over indoor environment problems, such as overly dry air, drafts, noise as well as increased heating energy consumption.

3.1.4 CAN/CSA F326

CAN/CSA F326 - M91 defines mechanical ventilation system performance for single-family dwellings. However, the 1995 National Building Code refers to conformance to CAN/CSA F326 - M91 as an option for Part 9 buildings and for self contained mechanical ventilation systems serving only one dwelling unit in Part 6 buildings.

CAN/CSA F326 - M91 specifies "minimum ventilation capacities" on a room-by-room basis for bedrooms, living rooms, dining rooms, kitchen bathrooms, utility rooms, etc. The minimum ventilation capacity is defined as the minimum rate, averaged over 24 hours of outdoor air which the ventilation system is capable of supplying. Unlike the ASHRAE Standards, air infiltration cannot contribute some or all of the air necessary to meet these ventilation rate requirements. The systems must supply these rates of outdoor air continuously, or averaged on a 24-hour basis, with some exceptions for re-circulated air.

The ventilation rates calculated for the typical one-, two-, and three-bedroom apartments are based on 10 L/s for the master bedroom, 5 L/s for each additional bedroom, and 5 L/s for each of one dining room, one living room, one kitchen, and one bathroom. No other rooms were included. The Standard specifies that ventilation rates are determined as if living rooms, dining rooms, or kitchens are individual rooms whether they are combined or not.

These requirements for mechanical ventilation result in ventilation rates ranging from 15 to 10 L/s per person or 0.79 to 0.64 ach for the typical one to three bedroom apartments. These ventilation rates are higher than required by any of the ASHRAE Standards, with the greatest increase being for apartments with fewer bedrooms.

Ventilation rates are calculated based on the number of rooms, rather than floor area or number of occupants. Therefore increasing apartment size without increasing the number of bedrooms does not require a higher ventilation rate, resulting in lower ventilation rates when measured on an ach basis.

Using the example one bedroom apartment of two different sizes, a one bedroom 46.5 m^2 (500ft^2) apartment requires 15 L/s per person or 0.95 ach, while a larger 93 m^2 (1000ft^2) one bedroom apartment requires a ventilation rate of 15 L/s per person or 0.48 ach. For both size apartments these ventilation rates are significantly higher than required by any of the ASHRAE Standards.

CAN/CSA F326 - M91 also contains requirements for either continuous or intermittent exhaust capacities for bathrooms and kitchens. Intermittent exhaust capacities are identical to those required by ASHRAE Standard 62-99. Continuous exhaust capacity requirements are 30L/s (60 cfm) for kitchens or and 10 L/s (20 cfm) for bathrooms (compared to ASHRAE 62-01 requirements of 12 L/s for kitchens and 10 L/s for bathrooms). These exhaust capacities provide ventilation rates of 20 to 10 L/s per person and 1.06 to 0.64 ach for the typical one to three-bedroom apartments, with the lower rates corresponding to apartments with increasing numbers of bedrooms. For larger size apartments these exhaust capacities will provide lower ventilation rates on an air change per hour basis.

When applied to small apartments the ventilation rates required by F326 are much higher than specified by ASHRAE Standards. This may be because F326 is intended to define ventilation requirements for single-family houses, and single-family houses are typically much larger in floor area than apartments.

3.1.5 1995 National Building Code

3.1.5.1 Part 3 Buildings

The 1995 National Building Code (NBC) requires rates of supply of outdoor air to comply with ASHRAE Standard 62-1989 for all part three multi-family buildings (as do most provincial codes).

3.1.5.2 Part 9 Buildings

Part 9 multi-family buildings (3 stories or less in height and a building area not more than 600 m^2) require either adherence to CAN/CSA F326, or to have a mechanical ventilation system with a "Total Ventilation Capacity" calculated using a method that is essentially identical to that required to determine the "Minimum Ventilation Capacity" defined in CAN/CSA F326. Therefore the one-, two-, and three-bedroom apartments will require the same ventilation rates of outdoor air as calculated in Section 3.1.4, however there are no requirements for continuous operation; therefore they are difficult to compare to continuous ventilation rates required by other standards.

Part 9 of the 1995 NBC also contains requirements for intermittent exhaust capacities for a principal exhaust fan, and exhaust fans for kitchens and bathrooms. The principal exhaust fan must have a capacity equal to at least 50% of the Total Ventilation Capacity. Intermittent exhaust capacity requirements of 50L/s (100 cfm) for kitchens and 25 L/s (20 cfm) for bathrooms are also required, unless the principal exhaust fan is already used in one of these locations. The kitchen and bathroom intermittent exhaust capacities are identical to intermittent exhaust capacities required by both F326 and ASHRAE Standard 62-01 (but are much higher than F326 or ASHRAE Standard 62-01 continuous exhaust capacities). Neither the principal, kitchen, nor bathroom exhaust systems are required to run continuously.

3.1.6 Ontario Building Code 1997

The Ontario Building Code (OBC) 1997 has the same Part 9 requirements for "Total Ventilation Capacity" as NBC 1995, however the principal exhaust fan is specified as a fixed rate, depending on the size of apartment, rather than equal to 50% of the "Total Ventilation Capacity". It requires a principal exhaust fan capacity of 15, 22.5, 30, and 37.5 L/s for 1,2,3,4 bedroom apartments respectively. There are no requirements for continuous operation.

The OBC 1997 does not set minimum exhaust capacities for Part 9 kitchens; however it has a requirement for exhaust air from washrooms in Part 6 buildings that is higher than most Part 9 codes. Section 6.2.3.9 (12) of the Ontario Building Code requires an exhaust capacity of 24 l/s for each water closet, urinal, or shower. This means that a bathroom with a shower and toilet would require an exhaust capacity of 48 l/s. Section 6.2.3.9 (8) also says that exhaust ducts serving washrooms have to be independent of other exhaust ducts.

3.1.7 BC Building Code 1998

The BC Building Code 1997 Part 9 has no requirements for a "Total Ventilation Capacity". However it has requirements for a "Principal Exhaust Fan Ventilation Rate" that is specified as a fixed rate, depending on the size of apartment, with rates similar to those required by the OBC. It also has requirements for either continuous operation of the principal exhaust fan, or control for a minimum of two, four-hour operating periods per day.

BCBC 1998 also requires an exhaust fan in every kitchen with a minimum intermittent capacity of 40 L/s, and exhaust fans in each bathroom at either 25 L/s intermittent, or 10 L/s continuous.

3.1.8 ASTM Subcommittee E6.66 and ISO TC59/SC15, Performance Criteria for Single Family Attached and Detached Dwellings

A set of performance guides for housing are being developed in the US with ASTM and internationally with ISO. ASTM Subcommittee E6.66, *Performance Standards for Dwellings* is in the process of developing a set of residential performance standard guides for one and two family dwellings. A related effort is being pursued by ISO TC59/SC15 entitled, *Performance Criteria for Single Family Attached and Detached Dwellings*. The ASTM E6.66 draft guide currently under development specifies that the whole building outdoor air change rate should be consistent with ASHRAE Standard 62-01, that is 0.35 ach or 7.5 L/s per person, whichever is greater. It specifies that in terms of reliability, this rate should be achievable under all conditions of weather and building operation.

3.1.9 Contaminant Dilution to Exposure Guideline Limits (ASHRAE 62-01 Indoor Air Quality Procedure)

The ASHRAE Standard 62-01 Indoor Air Quality procedure provides a direct solution to control of indoor contaminants by restricting the indoor concentration of all known contaminants of concern to some specified acceptable levels. It provides two tables containing acceptable concentration levels at set exposure times for a limited list of contaminants, based on levels set by other bodies. The contaminants listed include:

- Sulphur Dioxide,
- Particulate (PM10),
- Carbon Monoxide,
- Ozone,
- Nitrogen Dioxide,
- Lead,
- Human Bio-effluents,
- Chlordane, and
- Radon Gas.

Standard 62-01also discusses a number of other potential contaminants for which definite acceptable limits have not been set. Exposure guidelines for these and other contaminants are also available from Health Canada and other bodies.

The Indoor Air Quality Procedure does not specify how contaminant concentrations are controlled and therefore does not require minimum ventilation rates. Contaminant control can typically be achieved with any or all of source control, source exhaust, or dilution.

In this study the ventilation rates required to dilute a number of example contaminant sources to acceptable levels were determined for the typical one-, two-, and three-bedroom apartments. The example pollutants chosen were based on the availability of information on typical source strengths, acceptable exposure limits, and typical ambient contaminant concentration levels. Without all three pieces of information, it is not possible to calculate the rate of dilution ventilation required.

3.1.9.1 Bio-effluent Control Based on Odour

Biological contaminants include viruses, bacteria, fungi, pollen, insect and animal excreta, and animal dander. Quantitative source strengths of biological contaminants are lacking due to the difficulty in testing concentration levels and designing test methods approximate the emission of bio-aerosols in buildings. Generally the measurement of bio-effluent control has focused on the control of odour instead.

ASHRAE Standard 62-01refers to laboratory and field studies by Berg-Munch et al. (1986), Cain et al. (1983), Fanger and Berg-Munch (1983), Iwashita et al. (1989), and Yaglou et al. (1936) that have shown that with sedentary persons, about 7.5 L/s per person of outdoor air will dilute odours from human bio-effluents to levels that will satisfy a substantial majority (about 80%) of un-adapted persons (visitors) to a space.

This requirement for 7.5 L/s per person is identical to that required by the ASHRAE Standard 62-01Ventilation Rate Procedure, resulting in the same ventilation requirements for the typical one, two, and three bedroom apartments.

3.1.9.2 Bio-effluent Control Based on CO_2 Concentration

The Indoor Air Quality Procedure of ASHRAE Standard 62-01 suggests that CO_2 can be used as an indicator of bio-effluent control. Based on field study results that show that 7.5 L/s per person of outdoor air will dilute odours from sedentary occupants to acceptable levels, it can be calculated that the corresponding differential concentration of CO_2 will be approximately 700 ppm.

Ventilation rates required to provide bio-effluent control for other activity levels were calculated using a simple mass balance between the outdoor air flow rate and production of CO_2 for average persons at various activity levels, while maintaining a steady state CO_2 concentration below 700 ppm. The ventilation rates required to control C02 levels to 700 ppm above ambient while sleeping can be reduced to 4 L/s per person, but must be increased to 12 L/s per person while walking and to 24 L/s per person while doing heavy work. In our typical apartments this corresponds to 0.21 to 0.26 ach while sleeping, and 1.3 to 1.5 ach while doing heavy work. The ventilation rates required to dilute CO_2 from persons doing heavy work are higher than continuous ventilation rates required by any of the standards discussed previously, but mostly in the range of intermittent exhaust capacity requirements.

3.1.9.3 TVOC Emissions From New Carpet

The quantity of ventilation required to dilute total volatile organic compound (TVOC) emissions from new carpet to acceptable levels was calculated assuming new carpet was installed over the entire floor area of the typical one-, two-, and three-bedroom apartments.

The source strength of TCOC emissions was assumed to be 5.0 mg/m2 hr, based on the Carpet and Rug Institute IAQ labelling program (CCI/CRI IAQ Limit) upper limit on TVOC emissions. Low emission carpets that meet this limit can display the Green IAQ Label, however many products have higher emissions.

There are no defined TVOC limits set by Health Canada or the US EPA, however a limit of 500 μg/m^3 was assumed based on the upper end of common guidance. A California Department of Health Services Review (1996) of relevant guidelines addressing VOC exposures highlights the European total VOC (TVOC) *comfort rang*e, based upon work of Mølhave, at <200 μg/m^3 as being a health conservative guideline. Other values addressing reasonable guidance for upper limit exposure levels for TVOCs include the Seifert target number of 300 μg/m^3 , the Tucker guidance number of < 500 μg/m^3 , and the State of Washington indoor air specification for new buildings of 500 μg/m^3.

An ambient level of 100 μg/m^3 TVOC was chosen based on the middle of the reported range of 10 to 211 μg/m^3 measured at 68 sites in the US by Shields and Fleisher (1993).

The resulting ventilation rates required to dilute TVOCs to acceptable concentration levels are 0.51 ach, falling somewhere between the requirements of ASHRAE Standard 62-01 and CAN/CSA F326. The air change rate remains constant for each apartment because emission levels are related to floor area. On a per person basis the ventilation rates required range from 9.7 to 8.1 l/sec.

If the acceptable TVOC exposure limit was reduced to 200 μg/m^3 as suggested by the lower limit of guidelines, ventilation rates would have to be increased to 2.0 ach, a rate much higher than continuous ventilation rates required by any of the standards or guidelines discussed previously.

3.1.9.4 CO Emissions From Gas Ovens

Emmerich and Persily (1996) conducted a literature review on residential indoor pollutant source strengths, and compiled results from studies reporting measured source strengths for nitrogen dioxide (NO_2), carbon monoxide (CO), particulates, biological contaminants, and volatile organic compounds. Based on a DOE (1990) report on combustion source strengths of CO, NO_2, and particulates from kerosene space heaters, gas space heaters, gas appliances, and cigarettes, they identified middle of the range source strengths of CO, NO_2, and particulates. These middle of the range source strengths were used in this study to calculate the quantity of outdoor ventilation air required for dilution to acceptable levels.

The source strength of CO emissions from an oven was assumed to be 1900 mg/hr based on the middle of the range of measured results reported in the DOE (1990) report. Health Canada (1989) has established an acceptable short-term exposure range (ASTER) for CO in residential occupancies of 11 ppm averaged over eight hours and 25 ppm averaged over one hour. They also report measured ambient outdoor levels of CO between 0.05 and 0.9 mg/ m^3 in rural areas and typical ambient outdoor levels of CO in urban environments of 1.1 to 11 mg/ m^3. An ambient level of 5 mg/ m^3 was assumed.

Assuming the gas oven is operated without operation of an exhaust hood, ventilation rates required to dilute CO to the one hour exposure limit for the one to three-bedroom apartments range from 11.2 to 5.6 L/s per person or 0.59 to 0.36 ach, generally falling between requirements for continuous ventilation rates required by ASHRAE Standard 62-01 and CAN/CSA F326.

If it is assumed that the oven is operated for 8 hours and emissions are maintained to the tighter 8 hour ASTER, then ventilation rates of 35 to 18 L/s per person or 1.9 to 1.1 ach are required, a rate much higher than continuous ventilation rates required by any of the standards or guidelines discussed above, but within the range of intermittent exhaust capacity requirements.

3.1.9.5 NO_2 Emissions From Gas Ovens

The source strength of NO_2 emissions from an oven were assumed to be 160 mg/hr based on the middle of the range of measured results reported in the DOE (1990) report. Health Canada has established an ASTER for NO_2 in residential occupancies of 480 $\mu g/m^3$ averaged over one hour. They report that background levels of NO_2 in rural environments in North America are less than 19 $\mu g/m^3$, and measured average nitrogen dioxide annual means for Canadian urban centres decreased from 60 to 44 $\mu g/m^3$ between 1977 and 1981. An ambient level of 44 $\mu g/m^3$ was assumed.

Again assuming that the gas oven is operated without operation of an exhaust hood, ventilation rates required to dilute NO_2 to the one hour exposure limit for the one to three-bedroom apartments range from 51 to 26 L/s per person or 2.7 to 1.6 ach, rates much higher than continuous ventilation rates required by any of the standards or guidelines discussed above, and also higher than intermittent exhaust capacity requirements.

3.1.9.6 Fine Particulate Emissions From Gas Ovens

The source strength of fine particulate emissions from an oven was assumed to be 0.2 mg/hr based on the middle of the range of measured results reported in the DOE (1990) report. The Health Canada ASTER for fine particulate matter (less than 2.5 µm) in residential indoor air is 100 $\mu g/m^3$ averaged one hour. Sinclair et al (1990) report an average measurement of fine particulate concentrations in four US cities as 13 $\mu g/m^3$. This was assumed as an ambient level in this study.

Ventilation rates required to dilute fine particulates to the one hour exposure limit for the one to three bedroom apartments range from 0.3 to 0.2 L/s per person or 0.02to 0.01ach. These ventilation rates are much lower than required by any of the ventilation standards or guidelines discussed above.

3.2 Ventilation Rates Required for Typical 1, 2, & 3 Bedroom Apartments

Based on the discussion presented in the previous section, a summary of ventilation rates required by existing codes, standards, and guidelines, as well as for dilution of several example indoor pollutant sources are shown in Table 2.

Table 2 - Ventilation Rates Required for Typical 1, 2, & 3 Bedroom Apartments

	One Bedroom			Two Bedroom			Three Bedroom		
	(L/s) (1)	(L/s-pers) (2)	(ach)(3)	(L/s) (1)	(L/s-pers) (2)	(ach) (3)	(L/s) (1)	(L/s-pers) (2)	(ach) (3)
1) ASHRAE 62-01 Ventilation Rate Procedure									
Requires higher of (a) or (b) for outdoor air ventilation rates and (c) or (d) or (e) for exhaust capacities.									
a) Ventilation rate of 0.35 ACH outdoor air (including infiltration).	13.2	6.6	0.35	17.6	5.9	0.35	22.0	5.5	0.35
or,									
b) Ventilation rate of 7.5 l/s (15 cfm) per person outdoor air (incl. infiltration).	15	7.5	0.40	22.5	7.5	0.45	30	7.5	0.48
and,									
c) Cont Exhaust Capacity - Kitchen 12L/s (25 cfm) and Bathroom 10 L/s (20 cfm)	22	11.0	0.58	22	7.3	0.44	22	5.5	0.35
or,									
d) Inter Exhaust Capacity - Kitchen 50L/s (100 cfm) and Bathroom 25 L/s (50 cfm)	75	37.5	1.99	75	25.0	1.49	75	18.8	1.19
or,									
e) Openable Windows in kitchen and bathroom.									
2) ASHRAE 62.2P - Low Rise Residential Buildings									
a) Public Review Draft, Aug, 2000 - Minimum whole house total mechanical ventilation rate of 7.5 L/s (15 cfm) per person plus 5 L/s per 100 m^2 (1 cfm per 100 ft2) conditioned floor area, plus an assumed infiltration rate (or credit) of 5 L/s per 100 m^2 (1 cfm per 100 ft^2) of conditioned floor area.	20.6	10.3	0.54	29.9	10.0	0.59	39.3	9.8	0.62
b) Recommended Revisions to 62.2P, Feb, 2001 - Minimum whole house total mechanical ventilation rate of 3.75 L/s (7.5 cfm) per person plus 5 L/s per 100 m^2 (1 cfm per 100 ft2) conditioned floor area, plus an assumed infiltration rate (or credit) of 10 L/s per 100 m^2 (2 cfm per 100 ft2) conditioned floor area.	15.9	7.9	0.42	22.4	7.5	0.44	28.9	7.2	0.46
3) CAN/CSA F326 - M91									
a) Minimum ventilation system outdoor air supply capacity, assuming bedrooms plus one each of LR, DR, Kitchen, & Bathroom (not including infiltration).	30.0	15.0	0.79	35.0	11.7	0.70	40.0	10.0	0.64
or,	40	20.0	1.06	40	13.3	0.79	40	10.0	0.64
c) Inter Exhaust Capacity - Kitchen 50L/s (100 cfm) and Bathroom 25 L/s (50 cfm)	75	37.5	1.99	75	25.0	1.49	75	18.8	1.19
4) 1995 National Building Code Part 9									
a) Total Ventilation Capacity (Equal to 3a)	30.0	15.0	0.79	35.0	11.7	0.70	40.0	10.0	0.64
b) Principal Exhaust Capacity - 50% of Total Ventilation Capacity	15	7.5	0.40	17.5	5.8	0.35	20	5.0	0.32
c) Other Int Exhaust Capacity - Kitchen 50L/s (100 cfm) and Bathrm 25 L/s (50 cfm)	75	37.5	1.99	75	25.0	1.49	75	18.8	1.19
5) ASTM Subcommittee E6.66 Performance Standards for Dwellings, and ISO TC59/SC15, Performance Criteria for Single Family Attached and Detached Dwellings - under development.									
Consistent with ASHRAE Standard 62, requires 0.35 ach or 7.5 L/s of outdoor air, whichever is greater (including infiltration).	15	7.5	0.40	22.5	7.5	0.45	30	7.5	0.48
6) Contaminant Dilution (ASHRAE 62-01 Indoor Air Quality Procedure)									
a) Bio-effluent control for odour - Field studies of dilution of bio-effluents required to satisfy 80% of un-adapted persons - rates based on 7.5 L/s per person.	15.0	7.5	0.40	22.5	7.5	0.45	30.0	7.5	0.48
b) Bio-effluent control based on a differential CO_2 conc. of less than 700 ppm.									
Sleeping (0.7 met)	8.1	4.0	0.21	12.1	4.0	0.24	16.2	4.0	0.26
Light Office Work (1.2 met)	14.8	7.4	0.39	22.1	7.4	0.44	29.5	7.4	0.47
Walking (2.0 met)	23.8	11.9	0.63	35.7	11.9	0.71	47.6	11.9	0.76
Heavy Work (4.0 met)	48.6	24.3	1.29	72.9	24.3	1.45	97.2	24.3	1.54
c) New carpet TVOC emissions - TVOC emissions of 0.5 mg/m^2 hr (CCI/CRI IAQ Limit) from carpet covering all floor area, maintained to conservative exposure limit target of 500 micro g/m^3, with an ambient TVOC level of 100 micro g/m^3.	19.4	9.7	0.51	25.8	8.6	0.51	32.3	8.1	0.51
d) Gas oven CO emissions - Medium source strength CO emissions of 1900 mg/hr maintained to Health Canada acceptable short term exposure limit of 28.5 mg/m^3 averaged over one hour, with an urban ambient CO level of 5 mg/ m^3.	22.5	11.2	0.59	22.5	7.5	0.45	22.5	5.6	0.36
e) Gas oven NO_2 emissions - Medium source strength NO_2 emissions of 160 mg/hr maintained to Health Canada acceptable short term exposure limit of 480 micro g/ m^3 averaged over one hour, with an urban ambient NO_2 level of 44 micro g/ m^3.	101.9	51.0	2.70	101.9	34.0	2.02	101. 9	25.5	1.62
f) Gas oven fine particulate emissions - Medium source strength fine particle emissions of 0.2 mg/hr maintained to Health Canada acceptable short term exposure limit of 100 micro g/ m^3 averaged over one hour, with an urban ambient fine particulate level of 13 micro g/m3.	0.6	0.3	0.02	0.6	0.2	0.01	0.6	0.2	0.01

Notes:

(1) Ventilation flow-rate, measured in litres/second (L/s).

(2) Ventilation flow-rate measured on a per person basis (L/s-person), assuming 2 persons for the first bedroom and one person per additional bedroom.

(3) Ventilation flow-rate measured in terms of air changes per hour (ACH) based on the assumed typical apartment size with 8 ft ceiling height.

3.3 Additional Factors Affecting Recommended Ventilation Rates

3.3.1 Ventilation Modelling

A low air pollutant level in a space is dependent on four factors. High outside concentrations of pollutants, high source strengths, low ventilation effectiveness values or low ventilation rates can each contribute to high indoor pollutant levels. The equation governing the concentration of air pollutants in a space is:

$$Ci = Co + N/(kV)$$

Where:

Ci	concentration of the pollutant inside the space (g/ m^3)
Co	concentration of the pollutant at the source of the ventilation air (usually, but not always, outside air) (g/ m^3)
N	pollutant source strength in the space(g/s)
k	ventilation effectiveness (k = 1.0 for well mixed air; k can be greater(~1.4) for a well designed displacement ventilation system, or k can be less (approaching zero for a ventilation system with severe short-circuiting between supply and exhaust)) (dimensionless)
V	ventilation rate (m^3/s)

In determining acceptable ventilation rates, the concentration of pollutants in outside air is assumed to be negligible. This assumption for outdoor pollutants is questionable, particularly in large cities or towns where levels of NOx, SOx, diesel fumes, and particulates may be significant. Placing air intakes at the upper parts of buildings can lower the concentration of outdoor pollution compared to ground level. Probably the worst location for air intakes in a MURB is at ground level near a loading dock. Providing adequate separation between air intakes and exhausts is good practise. If outdoor pollutant concentration is not zero, then ventilation rates must be increased beyond the base level.

The indoor pollutant source strength term (N) is comprised of many factors—human bio-effluents including carbon dioxide and body odour; personal care product off-gassing of volatile organic compounds (VOCs) such as perfumes, deodorants, hair spray, anti-static agents; cleaning products, waxes, room deodorisers; tobacco smoke; dust from furnishings and carpeting; off-gassing from building materials and furnishings. Most of the work on pollutant source strengths related to appropriate ventilation rates has concentrated on carbon dioxide and bio-effluents. As discussed in section 3.1.9, based on the metabolic rates of humans [at 1.2 met units or light activity levels], if the maximum concentration of carbon dioxide in the space is to be limited to 1000 ppm, about 7.5 L/s of outside air is required per person in a well-mixed space.

High indoor air pollutant source terms can result during construction or renovation, when paints, varnishes, new carpets, millwork, etc. are applied. However, it would be costly to incorporate a ventilation system that could handle all the extra ventilation required to dilute the indoor air pollutants caused by the relatively short time scale associated with the construction or renovation. While contaminant controlled ventilation systems are available, they are costly and require operation and maintenance levels that are not presently provided in typical MURBs. What can be concluded from this discussion is that it is not practical to design ventilation systems to dilute all contaminants. Ventilation systems in MURBs should be designed to provide fixed rate dilution for people-related effluents, with the building designed to minimise the generation of other pollutants.

Improving the ventilation effectiveness (k) will reduce concentration of pollutants without changing the ventilation rate. It is not enough to provide a ventilation supply at one location in the suite and expect that the air will be distributed effectively. Even if existing ventilation systems for apartments did supply outdoor ventilation air from the pressurised hallway around the perimeter of the entrance door, and the air was exhausted through the kitchen and bathrooms (as currently falsely believed by many owners, managers, and occupants), it would bypass the living rooms and bedrooms where it is needed most. When internal doors to bedrooms are closed, the ventilation effectiveness can be low. Means of ensuring better ventilation effectiveness throughout the apartment include providing either a supply and/or exhaust duct in each room, or providing ventilation air to a fan coil unit that distributes ventilation air along with air for heating/cooling to each room in the apartment. If ventilation effectiveness is reduced, then ventilation rates must be increased to overcome the loss in ventilation effectiveness.

3.3.2 Equipment and Operating Cost Considerations

Mechanical ventilation is costly to provide. The costing manual provided by Hanscomb (Yardsticks for Costing 2000, Cost Data for the Canadian Construction Industry) has a cost for ventilation systems [make-up air systems, including fan, heating coil, duct, diffusers, thermal insulation and controls] in the range of $25 per L/s of air flow. These costs do not include other components such as exhaust systems, air cooling, boilers, heat recovery, variable volume flow rates, or the cost of the building volume to house the equipment.

The operating energy associated with mechanical ventilation is also substantial, including the heating, cooling, and fan motors energy. For example, the heating cost for 1 L/s of ventilation air provided continuously in southern Saskatchewan using current natural gas prices and typical boilers is about $6 per year.

3.3.3 Humidity Control

In most of Canada, high ventilation rates in the heating season can have negative IAQ implications, in that the indoor relative humidity in the building can fall to low levels. For example, a MURB ventilation system in a renovated apartment building in Prince Albert, Saskatchewan, which featured a measured average ventilation rate of 39 L/s per suite, was found to have indoor relative humidity (RH) levels as low as 4% during the winter. Health Canada recommends a winter indoor RH level of 30%-55% unless constrained by window condensation. A graph showing the indoor relative humidity in the Prince Albert building is presented in Figure 2. For this building, the indoor RH was less than 30% for more than 80% of the year. Humidification can be added to the ventilation air, but the additional capital, energy and maintenance costs are substantial, as are the IAQ risks (moulds, fungi, bacteria) from excessive moisture. Similarly, under-ventilation leading to high humidity problems is a problem in many MURBs.

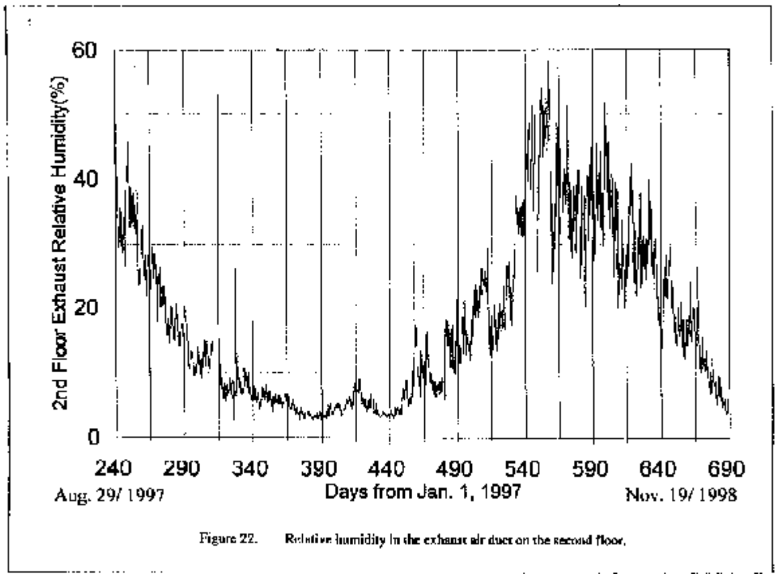


Figure 2: Indoor Relative Humidity in a Building With a Ventilation Rate of 39 L/s

3.4 Recommended Ventilation Rates For MURBs

The previous analysis points out that ventilation rates required by relevant standards vary significantly, as well as the portion of ventilation expected to be provided by infiltration. It also shows that ventilation rates required to dilute pollutants can be high, source strengths are highly variable and can require dilution ventilation rates that are much higher than required by existing standards, and acceptable exposure limits are not well defined. In the context of balancing the requirements to dilute contaminants, reduce capital and operating costs and avoid low RH levels, ventilation rates in the range of 7.5 L/s per person are recommended. The ASHRAE 62-01 Ventilation Rate Procedure provides the above recommended ventilation rates if the ventilation rates are provided by mechanical systems rather than relying on infiltration through exterior envelopes as assumed in the Standard.

There may be considerable periods throughout the year in MURBs when stack and wind effect are zero, and the only ventilation provided is by the mechanical ventilation system. Therefore, it is recommended that ventilation be provided completely through mechanical systems rather than assuming a portion of outdoor ventilation air is provided through infiltration.

For the above rate of mechanical ventilation to effectively reach occupants, compartmentalisation and increasing air tightness between units and floors and within the building envelope (including sealing between units and corridors) are essential parts of any ventilation strategy. Also ventilation air should not transfer from one suite to another to be re-used or re-circulated unless measures are taken to clean the air. With current technology, this rules out the re-circulation or re-use of air in MURBs. (This practise of re-circulating air is almost universally used in commercial and institutional buildings as a strategy for providing sufficient air volumes for air conditioning and space heating.)

4 Identifying Alternative Ventilation Strategies

4.1 Performance Parameters for Alternative Systems

The research team identified practical characteristics of ventilation systems that should overcome the problems of conventional systems discussed in Chapter 1. These characteristics are listed in Table 3, grouped into the following eight categories:

1. Ventilation performance
2. Capital and operating costs
3. Maintenance
4. Fire/smoke control
5. Noise issues
6. Comfort
7. System issues
8. Owner/designer construction issues

These performance parameters were used to help develop the four alternative ventilation systems evaluated later in this study.

Table 3: Ventilation System Performance Parameters, Targets and Strategies

Performance Parameter	Target or Strategy
Ventilation Performance	
1. Minimum outdoor air ventilation rates	➢ Continuous ventilation: One bedroom apartments – 15 L/s Two bedroom apartments – 22.5 L/s Three bedroom apartments – 30 L/s
2. Outdoor air exchange rates under varying wind/stack conditions.	➢ Minimum effect of stack/wind on air supply/exhaust rates - using systems that can counteract wind and stack effects, or achieved through compartmentalised buildings.
3. Ventilation effectiveness	➢ Direct outdoor air supply to all living areas. ➢ Ventilation effectiveness of 1.0 or greater, where 1 is a fully mixed condition. ➢ Diffusers and return located to avoid short circuiting.
4. Supply air quality - filtration, percentage air recirculated, potential for contamination of intake air.	➢ Filtered ventilation air supply. ➢ 100% outdoor air. ➢ Air intakes away from outdoor pollutant sources.
5. Control of contaminant levels ➢ Ability to directly control humidity levels, CO_2 and other contaminants. ➢ Local intermittent exhaust capacity for control of humidity and point sources.	➢ Continuous background ventilation with a centrally located controls for intermittent high speed operation that can be easily operated by occupants. ➢ Local kitchen and bathroom exhausts. ➢ Minimum recommendation for intermittent flow rates – 50% increase over continuous flow-rates.
Capital and Operating Costs	

Performance Parameter	Target or Strategy
6. Equipment capital cost.	➢ Nominal increase in capital cost over conventional systems acceptable. ➢ Reduced life cycle cost compared to conventional corridor supply, kitchen and bathroom exhaust systems.
7. Energy to temper ventilation air - determined by ventilation rate and use of heat recovery.	➢ 10 to 20% reduction in ventilation energy consumed to temper ventilation air over conventional systems - achieved by using either heat recovery or improved systems without heat recovery.
8. Air Infiltration	➢ Suite NLA of 0.7 cm^2/m^2 wall area @ 10 Pa or 0.5 $L/s.m^2$ @ 75 Pa.
9. Fan energy consumption	➢ 4 cfm/W. Turning off system to save energy should not be credited. But turning down as opportunities present themselves may be credited.
10. Maintenance costs.	➢ Less than $50 to $75 per suite per year based on HRV's in houses.
Maintenance	
11. Level of maintenance required - cleaning, component replacement, reliability of equipment.	➢ Further study is required to set a target for operating hours between maintenance/replacement intervals.
12. Maintenance accessibility - mechanical room versus suite, inaccessible locations	➢ All equipment requiring maintenance located in easily accessible locations. Condos - in the suite, rental apartments - in mechanical rooms or hallways.
Fire/Smoke Control	
13. Fire integrity - control of smoke movement, ducts crossing fire-smoke separations.	➢ Design to increase integrity of fire and smoke prevention through minimising the need for fire dampers required for vertical ducts through floor-to-floor separations, and horizontal ducts from suite to hallway or to other spaces.

Performance Parameter	Target or Strategy
Noise Issues	
14. Noise Level ➢ Noise from local supply and exhaust fans ➢ Noise from central fans and ducts ➢ Air noise at grilles, diffusers, and corridor access doors ➢ Transmission of noise from corridors ➢ Noise transfer though central system ductwork	➢ 0.6 sone limit on local intermittent use fans. ➢ Minimal noise from grilles and diffusers. Typical design range for residential is an NC level of 25 to 35. Target should be 25 or lower. ➢ Door undercut not used as ventilation airflow pathway. ➢ Weather-stripped corridor access doors. ➢ Sound baffles/design to reduce noise transfer.
Comfort	
15. Cold drafts- supply air temperature, airspeed.	➢ Provide supply air at minimum 12 degrees C for high side wall diffusers and 18 degrees C for floor diffusers. ➢ Introduce supply air outside occupied zone (ie. Above head height or along walls).
16. Corridors too hot, too cold, or stuffy	➢ Minimum corridor ventilation rate of 0.05 cfm/ft2 based on ASHRAE Standard 62 – 1999 recommended minimum.
System Issues	
17. Suite pressure balance ➢ Avoid positive pressurisation creating building envelope condensation problems. ➢ Avoid excessive depressurisation leading to rain penetration or combustion spillage. ➢ Control odour transfer from corridors and other suites.	➢ Slight depressurisation of suites using balanced supply/exhaust systems. ➢ Eliminate combustion spillage susceptible appliances. ➢ Depressurisation limit to prevent rain penetration of 10 Pa.
18. Controllability - ability to reduce rates when space not occupied and increase for cooking, showering, etc. - occupant control, automatic control	➢ Condos - Low speed continuous ventilation rate plus user controls for intermittent high-speed ventilation, plus an off switch.

Performance Parameter	Target or Strategy
	➢ Rental apartments - Low speed continuous ventilation rate controlled centrally, plus user controls for intermittent high speed ventilation.
19. Complexity ➢ To operate ➢ To maintain	 ➢ Simple to use controls. ➢ Simple to maintain.
Owner/Designer Construction Issues	
20. Code compliance ➢ Fire and smoke control	 ➢ Corridors not used as ventilation ducts.
21. Space requirements - vertical and horizontal	➢ Ventilation system should not take up any more floor area than conventional systems.
22. Component availability	➢ Can be designed and constructed with commercially available equipment.
23. Integration into construction and commissioning process	➢ Smooth integration.
24. Flexibility	➢ One size fits all (or most) apartments.

4.2 Selection of Alternative Ventilation Systems

A large number of ventilation strategies are possible depending on whether the supply or exhaust system serves one suite, one floor, or the whole building, and whether or not supply or exhaust systems are passive or forced mechanical systems. In fact, thirty six different system types are possible when broken down this way, as shown in the matrix shown in Table 4.

Table 4: Matrix of Possible MURB Ventilation Strategies

		Mechanical Supply			**Passive Supply**		
		Suite	Floor	Central	Suite	Floor	Central
Mechanical Exhaust	Suite	√	√	√	√	√	√
	Floor	√	√	√	√	√	√
	Central	√	√	√	√	√	√
Passive Exhaust	Suite						
	Floor						
	Central				√	√	√

A description of the major design options is discussed below.

4.2.1 Mechanical Supply Ventilation Options

4.2.1.1 Suite

An individual supply fan delivers a continuous ventilation flow rate via ductwork to bedrooms and living areas. The same supply fan can also provide an intermittent high flow rate of supply. A separate central supply fan delivers corridor ventilation.

4.2.1.2 Floor

A variable speed supply fan operating at constant discharge pressure provides a continuous ventilation rate to all suites on one floor. Intermittent high flow to individual suites could be available using pressure reduction control on the supply duct to each suite in conjunction with an increase in flow from the floor based fan. Supply air is ducted to all bedrooms and living areas.

Supply ducts require fire dampers. Corridor supply air can be delivered by floor supply fans or by a separate system.

4.2.1.3 Central

A rooftop mounted variable speed fan operating at constant discharge pressure provides a continuous ventilation rate to all suites. Dampers at each floor could be automatically controlled on duct/floor differential pressure, to adjust for seasonal stack effect. Individual suite intermittent high flow could be available through the use of pressure reduction control on supply ducts to each suite in conjunction with an increase in flow from the main fan. Supply air is ducted to all bedrooms and living areas. Supply ducts require fire dampers. Corridor supply air can be delivered by the central supply fan or by a separate system. If the building's floor plate warrants, multiple central systems may exist.

4.2.2 Mechanical Exhaust Ventilation Options

4.2.2.1 Suite

One or more exhaust fans extracts a continuous flow rate and/or intermittent high flow rate from the kitchen and washrooms.

4.2.2.2 Floor

A variable speed exhaust fan operating at constant inlet pressure extracts a continuous flow rate from all suites on one floor. Individual suite intermittent high flow rate of exhaust could be available through the use of pressure reduction control on the exhaust duct from each suite in conjunction with an increase in flow from the floor based exhaust fan. Exhaust ducts from kitchen and bathrooms require fire dampers.

4.2.2.3 Central

A rooftop mounted variable speed fan operating at constant inlet pressure extracts a continuous rate of exhaust from all suites. Dampers at each suite could be automatically controlled on duct/suite differential pressure, to adjust for seasonal stack effect. Individual suite intermittent high flow could be available using pressure reduction control on the exhaust duct to each suite in conjunction with an increase in flow from the main exhaust fan. Exhaust ducts from kitchens and bathrooms slope upward to a vertical fire-rated shaft maintained under negative pressure by the central exhaust fan. Exhaust ducts extending in to a vertical exhaust shaft do not require fire dampers. To limit sloped duct runs, multiple vertical exhaust shafts may be employed.

4.2.3 Passive Supply Ventilation Options

4.2.3.1 Suite

Air is passively drawn into each suite by negative pressure via trickle vents on exterior walls or low pressure ductwork to bedrooms and living areas. Higher negative pressures induced passively or mechanically result in higher intermittent flow rates.

4.2.3.2 Floor

Air is passively supplied through low-pressure ductwork to bedrooms and living areas connected to a floor based supply vent. Passive supply requires fire dampers. Higher negative pressures induced passively or mechanically result in higher intermittent flow rates. Backdraft dampers are required to avoid flow reversal if a negative pressure differential is not maintained in some suites.

4.2.3.3 Central

Air is passively supplied through low pressure ductwork to bedrooms and living areas connected to a floor based supply vent. Passive supply ducts will require fire dampers. Higher negative pressures induced passively or mechanically result in higher intermittent flow rates. Backdraft dampers are required to avoid flow reversal if a negative pressure differential is not maintained in some suites.

4.2.4 Passive Exhaust Ventilation Options

Suite and floor based passive exhaust systems are not technically practical because they cannot take advantage of stack effect; therefore these systems were eliminated from further consideration. Also, systems with passive exhaust and mechanical supply would operate through mechanical pressurisation of suites. Pressurisation of residential suites is not recommended in colder climates (i.e. Canada) because pressurisation will force warm moist air through the building envelope, resulting in condensation related moisture problems. Therefore all systems with mechanical supply and passive exhaust were eliminated from further consideration.

4.2.4.1 Central

Air is passively exhausted through a central passive exhaust system, in conjunction with a passive supply system. An oversized central exhaust stack will operate under sufficient negative pressure during colder parts of the year. A flow sensor could be used to activate a mechanical fan in the exhaust stack when buoyancy forces are insufficient. Exhaust ducts from kitchens and bathrooms, slope upward to the vertical fire-rated shaft.

4.2.5 Supply Air Tempering

The alternative ventilation options described above assume that supply air with a minimum temperature of 12°C is delivered to the suites. Continuous flow rates are in the order of 15 L/s to 30 L/s, but intermittent flows may be double that amount. Mixing of supply air with room air is assumed to occur outside the occupied zone to avoid discomfort from low temperatures and drafts. To temper the air at variable outdoor temperatures in winter, the following strategies are practical[2]:

1. High effectiveness Heat Recovery Ventilators (HRV's) provides intrinsic variable preheat without overheating. This option requires supply and exhaust ducts at the building envelope to be in close proximity.
2. For intake and exhaust ducts remote from each other, run-around anti-freeze coils can extract heat from exhaust air and preheat supply air at an effectiveness of about 50%. In below freezing conditions, the antifreeze solution needs to be heated (centrally) to provide adequate supply temperatures.
3. Where heat recovery is not feasible, hydronic or electric in-duct heaters are required. Devices for low flows are not readily available and would be costly.

[2] Mixing boxes are practical alternatives to the options reviewed here, but were not analysed in the report.

Supply strategies employing direct inlets, tempering by dynamic effect, and solar preheat are not considered adequate to provide comfort in colder locations in Canada.

4.3 Performance Tradeoffs for Alternative Ventilation Strategies

Below is a discussion of the major issues identified for the alternative ventilation strategies relative to the performance parameters described in section 4.1. As can be seen, selection of alternative ventilation strategies is a creative process requiring trade-offs among the various performance parameters.

Table 5: Performance Tradeoffs for Alternative Ventilation Strategies

Wind/Stack Effect Resistance	• Mechanical systems are less affected by stack and wind effects than passive systems. • Suite and floor systems are better at avoiding problems with stack effects than systems with central exhaust or supply. • Suite based systems are less affected by wind effects than floor based or centrally based systems. • In floor based systems wall louvers will be affected by wind pressure making it difficult to get a variable ventilation system to work with a fine measure of control under conditions of varying inlet and outlet pressures. • Passive central supply systems will be affected by buoyancy forces from stack effect. • Balanced forced systems will be able to meet ventilation rates with relative insensitivity to the building air tightness. • Mixed systems (central with suite or floor) and passive systems are dependent on building envelope air tightness.
Supply Air Quality	• Filtering is difficult to incorporate into passive systems due to pressure losses.
Heat Recovery Feasibility	• Individual HRV's are more costly than central heat recovery. • Heat recovery is difficult to achieve in individual suite supply or exhaust systems combined with floor or central systems. • Central/central and floor/floor systems allow the use of larger and higher efficient equipment, but system losses are higher. • Passive/forced HRV requires custom HRV specification and is more costly • A consideration that will be increasingly important in the future is the ability to adapt systems with heat recovery as energy prices continue to rise.
Maintenance Costs and Accessibility	• Suite based HRV units have more filters to be cleaned/replaced. • Suite based HRV units have smaller fan motors that have shorter life than large motors.

	• Suite based HRV's could be accessible via access doors in hallways. • Maintenance in central mechanical rooms (for central and floor systems) result in less labour. • Simple systems are preferred that do not have control sensors such as humidistats, carbon dioxide sensors, and pressure difference sensors. None of these sensors have a track record of low-maintenance and durability, and multi-family complexes generally do not have an on-site maintenance person with skills in diagnosing sensor systems.
Fire/ Smoke control	• Suite based systems don't required smoke dampers. Fire dampers are required at suite penetrations.
Fan Noise	• Good design, careful component selection and high quality installation can result in low noise performance for any system. • Floor based systems will have larger fans (and potential noise problems) on each floor level.
Noise transfer	• The fewer suites that are connected to a duct system the better. Therefore suite-based systems are preferred over central systems.
Comfort	• Systems with no air tempering (such as passive air inlets) will create cold drafts. This is not acceptable in colder parts of the country.
Suite Pressure Balance	• Mechanical supply with passive exhaust is not desirable in cold climates because pressurisation will force warm, moist air through the building envelope, resulting in condensation-related moisture problems. • Odour transfer from suite to suite is more likely with systems that rely on positive pressure supply and passive exhausts. Suites can be made relatively tight to prevent odour transfer, but usually they are not. • Central systems have poorer pressure control and stack effects affect flow at individual suites. • With passive exhaust, the pressure balance will be variable. • With suite and floor passive supply and forced exhaust, the pressure regime will be consistent and slightly negative.
Controllability	• Central systems are harder to control at the suite level than suite and floor systems. • In rental buildings, central control may be desirable. • Central passive exhaust with forced supply is hard to control.
Space Requirements	• Suite systems require no footprint, as they are typically installed on ceilings or in closet space. • Floor systems may require a separate room on each floor (which may be used for another purpose, such as electrical room), but no vertical stacks. • Floor systems require ceiling space (presumably in the corridor) for horizontal duct runs. This will be difficult to accommodate where hydronic and/or hot and cold water pipes are also in the ceiling and almost impossible to accommodate both mechanical supply and exhaust systems because of crossovers. • Central forced/passive combination systems require more room than central forced/forced options due to larger ductwork. • Dropped ceilings in corridors are not popular as they make the corridors

	less pleasant spaces.

4.4 Case Studies of Buildings with Alternative Ventilation Systems

To date only a small number of MURBs have been built in Canada using alternative ventilation systems. Lessons learned from three projects that have been built are described below:

4.4.1 Conservation Co-Op, Ottawa, Ontario

Mechanical Designer: Leslie Jones and Associates.

Description	• Ducted supply and return roof mounted HRV units serving groups of 3 or 4 suites. • The HRV units provide continuous supply air to suite air handlers, and air is exhausted continuously from bathrooms and kitchens. • Each suite has a boost switch which increases ventilation rates. • Recirculating range hoods with charcoal filters are provided in the kitchens.
Lessons Learned	Positive • Consistent delivery of outdoor air to living areas resulting in good IAQ. • Significantly reduced energy costs relative to conventional units. • Successful integration of HRV units. • High interior sidewall diffusers can be used successfully to heat and ventilated well insulated, well sealed apartments. Areas for Improvement • Cross contamination of HRV inlet and exhaust result in odour transfer. • Undesirable airflow between hallways and suites. Suite access doors require weather stripping to eliminate this air flow path and reduce noise transfer. • Overheating in hallways in summer requiring higher forced ventilation rates. • Undesirable heating of outdoor supply air through HRV units in summer. This could be improved by operating in exhaust only mode during summer. • Duct shafts and chases serving apartments under a central strategy must be well sealed to prevent noise and odour transfer. • Use of forced air heating system fan coil units to distribute ventilation air makes use of existing ducting but conventional fan-motor operation costs can be considerable. A more in-depth description of the project and lessons learned is included in Appendix A.

4.4.2 LeClos St-Andre, Montreal, Quebec

Mechanical Designer: Denis Laviviere Experts-Conseils Inc.

Description	• Central ventilation system supplies air to all rooms. • A central heat recovery unit on the roof preheats fresh air using exhaust from kitchens, laundry, and bathrooms
Lessons Learned	Positive • Continuous ventilation with good IAQ in all spaces in the building • Continuous exhaust of all "wet" rooms • Good indoor air quality is affordable because of heat recovery • Single point of service. • Can cool, humidify, or dehumidify incoming outdoor air Areas for Improvement • Complexity of design and installation. • System was never balanced because it was too expensive and time consuming for the balancing contractor to arrange access to all rooms in all suites in a fully occupied condominium environment. • All apartments are aerodynamically connected, with no compartmentalisation possible. • Little ability for occupant control of ventilation – many tape over grills in rooms where too much ventilation was received while nothing much can be done to increase ventilation in rooms where more is required. • Dropped ceilings in corridors

4.4.3 Governors Road Project, Dundas, Ontario

Mechanical Designer: Enermodal Engineering

Description	• One HRV in each apartment interconnected to the forced air heating system • Corridors ventilated by HRV that supplies air to corridor and draws exhaust air from top of garbage chute. This ventilated corridors, contains odours, and provides opportunity for heat recovery
Lessons Learned	Positive • Good indoor air quality • Occupants have control and responsibility for operation and maintenance – works well in a condominium environment. • Individual units work well with individual metering of electricity and natural gas • System can be deactivated in apartments during extended absences • Low heat loss and appropriate heating system design allows

	ventilation without operation of system circulation fan. Areas for Improvement • Many holes in building envelope • Challenge to find sufficient clearance between supply, exhaust, combustion air, dryer, furnace vent, and hot water vent. • Many points of service (not too bad in a condominium environment).

4.5 Alternative Ventilation Systems Selected

After ranking all system combinations based on the above discussion points, the project team selected the following 4 systems which were felt to have the best potential for meeting the greatest number of performance parameters, while allowing a broad range of system types to be further evaluated:

Temperate Climate System
No supply tempering or passive supply tempering. Suggested only for use in regions less than 3500 heating degree days.

1. Passive suite supply and forced suite exhaust

Cold Climate Systems
Heat recovery or variable capacity electric/hydronic supply tempering on all systems.

2. Forced suite supply and forced suite exhaust
3. Forced floor supply and forced floor exhaust
4. Forced central supply and forced central exhaust

A detailed description of each of these systems is presented in the next section.

5 Analysis of Alternative Ventilation Systems

5.1 Ventilation System Descriptions

The four ventilation systems developed and analysed in this work are summarised in Table 6 below.

Table 6: Alternative Ventilation System Description

System	System Concept	Suite Ventilation System				Corridor Supply
		Supply Ducting And Fan	Exhaust Ducting And Fan	Controls	Heat Recovery	
Base Case	Passive suite supply, forced suite exhaust (Conventional corridor supply/ bathroom exhaust system)	Infiltration through windows, envelope, & door undercut.	Bathroom and kitchen exhaust fans	Manual bathroom and kitchen fan control	None	Separate Central System
1	Passive suite supply, forced suite exhaust	Exterior wall passive vents	Individual Suite	None	None	Separate Central system
2	Balanced forced suite supply, forced suite exhaust	Individual Suite	Individual Suite	None	15-30 L/s suite HRV units	Separate Central system
3	Balanced forced floor supply, forced floor exhaust	Floor	Floor	Suite Balance	250 L/s Commerci al Unit	Floor Ventilator
4	Balanced forced central supply, forced central exhaust	Central	Central	Supply and exhaust wind & stack	2250 L/s Unit	Central Ventilator

5.1.1 System 1 Passive Vents with Suite Based Mechanical Exhaust

Description
Fresh air is passively drawn from outside into each bedroom and the living room via linear registers installed on the exterior walls near ceiling level. Suite exhaust is removed via the bathroom(s) continuously at a rate of 15L/s, 22.5 L/s, and 30 L/s for 1, 2, and 3 bedroom suites respectively. The continuous exhaust provides the depressurisation required to draw an equivalent (assuming no suite leakage) rate of supply air through the passive wall vents.

Bathroom exhaust is achieved through continuous exhaust only, with no provision for increased intermittent flow rates. A separate kitchen exhaust system on manual control, ducted horizontally to the exterior with a motorised damper, is provided as an option at additional cost. A separate central supply fan delivers a minimum flow rate to meet corridor ventilation requirements only.

System Issues
This system is only recommended for temperate climates with less than 3500 heating degree-days where supply air preheating may not be required. The assumed passive inlet vents (or inlet ducts) need to demonstrate sufficient entrainment ability to provide adequate comfort during cold weather. Flow reversals can also occur causing condensation in cold weather. Passive supply systems without preheat are being used in regions such as Vancouver, which has a design temperature of -7°C, however the comfort issues associated with these systems have not been clearly evaluated to date.

For cold climates, tempering of the supply air is necessary, and heat recovery is desirable. Both are difficult propositions with this system.

For this system to work effectively, suites should be compartmentalised as much as possible with airtight separations to exterior, corridors, and adjacent suites.

5.1.2 System 2 Balanced Individual Suite HRV Units

Description
A heat recovery unit (HRV) in each suite delivers fresh outdoor air continuously at a rate of 15L/s, 22.5 L/s, and 30 L/s for 1, 2, and 3 bedroom suites respectively. The fan-forced supply is ducted to all bedrooms and the living room and is discharged near ceiling level. A separate exhaust fan in the HRV unit extracts an equivalent continuous flow rate from the washroom(s).

Bathroom exhaust is achieved through continuous exhaust only, with no provision for increased intermittent flow rates. A separate kitchen exhaust system on manual control, ducted horizontally to the exterior with a motorised damper, is provided as an option at additional cost. A separate central supply fan delivers a minimum flow rate to meet corridor ventilation requirements only.

System Issues
Filter cleaning and replacement and motor maintenance requires access to each HRV unit. It may be possible to install HRV units adjacent to corridors with an access door to the corridor for maintenance.

5.1.3 System 3 Balanced Floor By Floor System With Heat Recovery

A floor by floor mechanical supply, exhaust, and heat recovery system with constant speed supply and exhaust fans operating at optimum efficiency provides a continuous flow rate of 15 L/s, 22.5 L/s, and 30 L/s for 1, 2, and 3 bedroom suites respectively to all suites on one floor. Supply air is ducted to all bedrooms and the living room of each suite and is discharged near ceiling level. Supply ducts require fire dampers where they cross into suites. The exhaust fan extracts an equivalent continuous flow rate from the washroom(s) of each suite.

Corridor ventilation is delivered from the floor supply fan. Sound traps are included in all ducts crossing into suites to minimise noise transfer.

Bathroom exhaust is achieved through continuous exhaust only, with no provision for increased intermittent flow rates. A separate kitchen exhaust system on manual control, ducted horizontally to the exterior with a motorised damper, is provided as an option at additional cost.

System Issues
For a relatively small building floor plate, a single balanced ventilation unit can be located in the ceiling of a service room (garbage room, electrical room) and ducted via the corridor with a drop ceiling. Crossovers will reduce ceiling height in corridors, which can be minimised if small rectangular ducts are used.

Preheat is achieved with a commercial scale heat recovery ventilator or air heater. The small imbalance of supply over exhaust, resulting from the supply of corridor ventilation air from the floor-based fan, is advantageous to minimise cross contamination.

5.1.4 System 4 Balanced Central System with Heat Recovery

A constant speed rooftop supply fan operating at optimum efficiency provides a continuous flow rate of 15 L/s, 22.5 L/s, and 30 L/s for one-, two-, and three-bedroom suites respectively to all suites in the building. Supply air is ducted to all bedrooms and the living room of each suite and is discharged near ceiling level. Supply ducts may require fire dampers where they cross into suites[3].

A constant speed roof top high-efficiency fan extracts a continuous flow rate from the bathroom(s) of all suites. Exhaust ducts from bathroom(s) slope upward to a vertical fire-rated shaft maintained under negative pressure by the central exhaust fan. Exhaust ducts discharging

[3] This should be confirmed with the local code.

to a vertical shaft do not require fire dampers. To limit the distance for sloped duct runs, multiple vertical exhaust shafts may be employed.

A rooftop mounted heat recovery unit extracts heat from the exhaust air which is used to preheat the supply air. Corridor ventilation is delivered by the central supply fan. Sound traps are included in all ducts crossing into suites to minimise noise transfer.

Bathroom exhaust is achieved through continuous exhaust only, with no provision for increased intermittent flow rates. A separate kitchen exhaust system on manual control, ducted horizontally to the exterior with a motorised damper, is provided as an option at additional cost.

System Issues
The duct risers must be located such that heat recovery ventilation or heater unit(s) can be installed for preheat.

Preheat is achieved with a commercial scale heat recovery ventilator or air heater. The small imbalance of supply over exhaust, resulting from the supply of corridor ventilation air from the central fan, is advantageous to minimise cross contamination between suites.

A more detailed description of each system is provided in Appendix B.

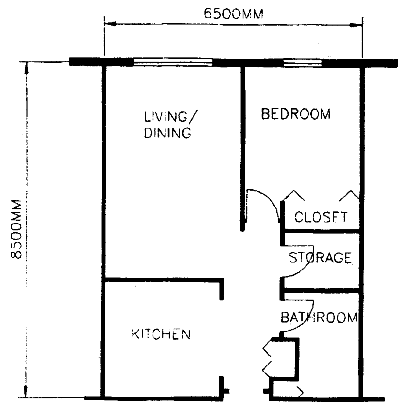
5.2 Analysis Assumptions

The four systems chosen for further analysis are assumed to be installed in accordance with industry "good practice" in a building envelope that is well insulated, with high-performance glazing, and tight construction for exterior walls as well as improved compartmentalisation of interior walls and floors. All systems provide continuous ventilation based on the ventilation rates recommended in Section 3.4.

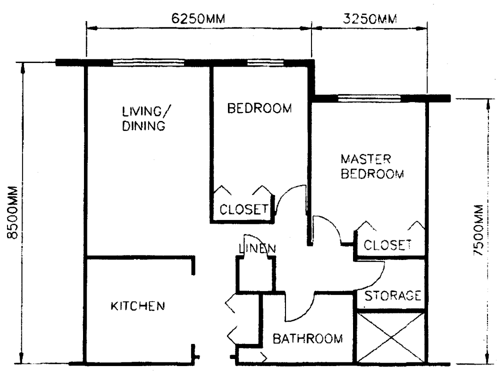
5.2.1 Building Characteristics

To quantify costs and energy consumption, a case study building was developed. The case study building is an 11-storey building with 10 residential floors. The ground floor and basement space are not part of this investigation. In order to estimate the heat load for the 10 residential floors, one floor of the building was modelled using ENERPASS. There are 10 suites on each floor, including three 1-bedroom suites, four 2-bedroom suites, and three 3-bedroom suites. Plans of the suites are shown in Figure 3. The floor plate is 48 m x 18.5 m, or 888 m^2, which includes space for elevators, stairs, etc. The floor has a double-loaded corridor running in the long direction with an area of 72 m^2. The 48 m long faces of the apartment building face north and south. The following parameter variations were modelled:

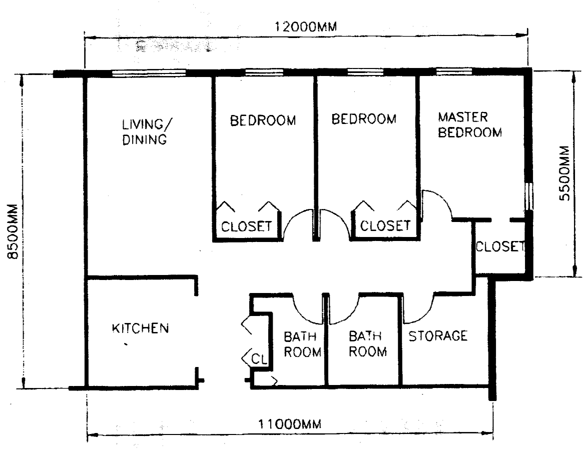
- A conventional corridor supply system and the alternative ventilation systems based on the four study systems described in the previous section.
- A "conventional" building envelope and a "good" building envelope.
- Climates of Vancouver, Toronto and Halifax.



1 BEDROOM SUITE
600 SQ. FT.
55 M^2



2 BEDROOM SUITE
800 SQ. FT.
74.5 M^2



3 BEDROOM SUITE
1060 SQ. FT.
99 M^2

Figure 3- Suite Layouts

The following are building envelope and ventilation system characteristics of the case study building:

5.2.1.1 Walls

Walls have insulation values of RSI 2.26 for the conventional walls and RSI 4.45 for the "good" walls.

5.2.1.2 Windows

The overall window area on north and south facing suite walls is 50% of wall area. The east and west facing corridor walls are also assumed to have 50% glazed area. For the conventional envelope, all windows are standard double-glazing with metal spacers and an RSI-value of 0.36 m^2 °C/W. For the good envelope, the north facing glazing is triple-glazed with double Low E coating, insulated spacer, argon filled, with an RSI-value of 1.23 m^2°C/W, and a solar heat gain coefficient (SHGC) of 0.5. The south facing glazing is the same except that shading was modelled by decreasing the SHGC to 0.2 through the use of shading devices. The window frame for the conventional envelope is aluminium and is 10% of the window area, with an RSI-value of 0.09 m^2 °C/W. For the good envelope, the frame is fibreglass with insulated cavities and is 10% of window area, with an RSI-value of 0.3 m^2 °C/W.

5.2.1.3 Interior Doors

There are five doors on each side of the corridor, each with an area of 2.2 m^2 between the corridor and the suites. The advanced ventilation system assumes tight suite doors. According to ASHRAE, the equivalent air leakage of a weather-stripped door is 8 cm^2/m^2 of door. Therefore, the equivalent air leakage area on each side of the corridor is 88cm^2 (8cm^2/m^2 x11m^2). The doors are assumed to have an RSI of 0.65 m^2 °C/W.

5.2.1.4 Infiltration Rates

The "conventional" and "good" building envelope configurations were assumed to have different outdoor air leakage values as summarised in Table 7.

Table 7: Case Study Building Air Tightness

Zone	Good Envelope		Conventional Envelope	
	L/s@ 75Pa	ACH @ 50 Pa	L/s@ 75Pa	ACH @ 50 Pa
Suite	18.7	0.06	37.4	0.12
Corridor	0.6	0.01	1.2	0.02

5.2.1.5 Heating Systems

Hydronic or electric baseboards provide zone heating for the case study buildings. The heating set-point in the suites is 22°C and 18 °C in the corridor. No cooling was modelled. The set-point for triggering outdoor air venting (i.e. opening windows) was set to 26°C.

5.2.1.6 Ventilation Rates

Suite Supply

For the conventional corridor supply /bathroom exhaust base case ventilation system, the outdoor air is supplied by the corridor at 50% of the installed bathroom fan capacity of 50 L/s per bathroom. This results in a building supply airflow of 2410 L/s. For the alternative ventilation systems, the suites are provided with 15 L/s, 22.5 L/s, and 30 L/s for each one, two, and three-bedroom suite respectively. This results in ventilation requirements of 112 L/s, and 113 L/s for each side of the corridor per floor and 0.25 L/s.m^2, or 18 L/s for each corridor. The building total ventilation rates are 2250 L/s for suites and 180 L/s for corridor as shown below.

Table 8: Continuous Suite Ventilation Rates

Suite	Area [Sq m]	Number of Suites	Continuous Ventilation Rate [L/Sec]	Total Building Ventilation Rate [L/Sec]
1 bedroom	56	30	15	450
2 bedrooms	75	40	22.5	900
3 bedrooms	100	30	30	900
Total				***2250***

Intermittent Exhaust

The issue of whether or not the four alternative ventilation systems should incorporate provision for manually operated intermittent high-speed ventilation (ie. high speed kitchen and bathroom exhaust) became a surprisingly contentious issue among members of the research team. The four systems selected are less complicated, have lower cost, and are more energy efficient if no provision for intermittent high-speed ventilation is provided. On the one hand, it can be argued that continuous ventilation rates will remove odour and smoke contaminants from bathroom and kitchens while providing fresh air to meet the needs of occupants, however it can also be argued that a higher rate of contaminant removal is desirable for some people, and necessary for removal of gas range contaminants. Continuous ventilation rates with no provision for intermittent high speed exhaust rates will meet the requirements of ASHRAE Standard 62-01, and the recommended ventilation rates from Section 3.4 However, some current provincial building codes require a minimum capacity rate for kitchen exhaust fans of 40 or 50 L/s.

In the end, specifications for the four alternative systems were developed that provide continuous ventilation only, with an option for each system for manually increasing the rate of exhaust. Another system and specification was developed for the option of adding a separate kitchen exhaust system that could meet code requirements.

Corridor Supply

All systems assume a forced corridor supply (at 0.25 L/s-m^2) to provide a measure of pressurisation. Desired heating, cooling and/or heat recovery can be added to the supply strategy.

5.2.1.7 Ductwork Layout

In each suite, all ventilation supply is ducted to bedrooms, and living/dining areas, at wall registers near the ceiling. Supply registers provide good mixing with room air. Exhaust is ducted from bathrooms through ceiling registers.

Directly ducting supply air to living areas assumes non-forced air space conditioning, that is, the use of hydronic or electric baseboard convection units or radiators.

However, it is common to duct ventilation air into the return of a vertical heating/cooling fancoil or a compact suite forced air-furnace with a hydronic or direct expansion coil in the supply duct. In this case the supply ductwork within the suite would be a single duct to the return of the air distribution device. Note that a minimum supply air temperature of 12°C is required to avoid heating equipment problems.

To allow ductwork material quantification and fan sizing for the purpose of this study, it was assumed that ducts within the suites are 100 mm diameter. The following additional assumptions and calculations were made:

Table 9: Duct Work Assumptions

Ductwork Section	Equivalent Length (m)	Air Speed (m/s)	Diameter (mm)	Pressure Drop (Pa)
Suite	30	2	100 - 125	20
Floor	150	2.5	125 - 250+	75
Central	45	4	300 - 600+	10

+ May be equivalent rectangular duct

Total pressure drops, in Pascals, for each system type are given in Table 10. A 20 Pa pressure drop has been added to account for registers. The values for HRV's were calculated for pressure drops based on a Des-Camps aluminium enthalpy wheels assuming a 1.5 m/s face (60 Pa) and entry and exit conditions (40 Pa).

Table 10: Pressure Drop for Each System [Pa]

System	Suite Ductwork	Floor Ductwork	Central Ductwork	Registers	Total Ductwork	HRV	Overall Total
1,2	20	--	--	20	40	100	140
3	20	75	--	20	115	100	215
4	20	75	13	20	128	100	228

#Not applicable to System 1

Acoustic separation for floor and central systems is achieved at each suite by using a flexible S-joint with interior insulation that offsets the main branch ductwork for supply and exhaust by a minimum of one diameter.

5.2.1.8 Design for Energy Efficiency

The specifications were developed with the intent of achieving cost-effective operation in the context of a "good practice" apartment building. The airtightness assumption of 1 ACH at 50 Pa is consistent with this approach. This means that the following additional assumptions have been made:

- Lower pressure ductwork with velocities for branch ducts are 2 m/sec (400 FPM) and main duct air velocity is 4 m/sec (800 FPM). Conventional ductwork is designed assuming an air velocity of 3 m/sec (600 FPM) for branch ducts and 4.5 m/sec (900 FPM) for the main duct. Using the equation:

$$\frac{\Delta P_2}{\Delta P_1} = \frac{V_2^2}{V_1^2} \times \frac{D_1}{D_2}$$

  the design static pressure of branch ductwork is conservatively reduced by 1/3 which, for the same flow, results in the ventilation load and fan size being reduced by 1/3.

- The fan efficiency in continuous operation is assumed to range from 35% for small (suite) fans to 50% for large (central) fans. To achieve these efficiencies, it is assumed that electronically commutated motors (ECM's) or adjustable speed drives (ASD's) are used. These technologies are able to maintain the peak efficiency automatically at loadings of 20% to 100% and are readily available. While there is an increased cost associated with these motors, the payback period is acceptable.

- Except in temperate climates (e.g. Vancouver), a supply preheat strategy is provided by heat recovery from exhaust at a minimum effectiveness of 75%. Typically in apartments with tight construction, plate-type heat recovery ventilators without moisture recovery are appropriate. All heat recovery cores are designed to have an air speed so as not to exceed 100 Pa external static pressure.

5.3 System Costs

5.3.1 Capital Costs

Capital and installation costs were calculated for a conventional system and each of the four alternative ventilation systems. Costs materials and labour for dropped ceilings, bulkheads, and access doors because to ignore them would not provide a true comparative cost.

The base case system is designed using a conventional approach to apartment ventilation with inexpensive bathroom exhaust fans ducted horizontally to the outside, no motorised dampers, and a conventional corridor supply system. The base case system does not include the cost of kitchen exhaust, to allow for a direct comparison to the analysis of alternative ventilation systems, that assume an option for kitchen exhaust. In all cases, system costing was calculated for all suites in the building plus the corridor ventilation system, and then normalised to provide costs on a per suite basis.

The additional cost of intermittent high speed ventilation was not completed. However, the cost of adding a kitchen exhaust hood with exhaust ducted horizontally to the outside is provided as an optional add-on. The kitchen exhaust system includes a motorised damper that prevents airflow though the ductwork when the fan is not in operation, so that the operation of the advanced alternative ventilation systems are not compromised by wind and stack effects.

System costs are summarised in Table 11. Detailed costing for each system is attached in Appendix D and Appendix E. As shown, at an average cost of $938 per suite, the conventional system is the least expensive. The incremental cost of advanced systems that supply a dedicated rate of ventilation air and overcome many of the problems of conventional systems range from a low of approximately $700 for system 1 to a high of $2,300 for system 2, with systems 3 and 4 in between.

Table 11: Summary of System Costs

System	Basic System	Optional Incremental Costs		
	Overall Cost (1)	Incremental (5) Cost of Advanced System	Kitchen Exhaust	Gas heat for corridor supply (7)
1. Suite passive supply, suite exhaust, no HRV	$1,675.00	$692.00	$1,238.00 (6)	$3,000.00
2. Suite balanced supply and exhaust with HRVs	$3,264.00	$2,281.00	$1,238.00 (6)	$3,000.00
3. Floor balanced supply and exhaust with HRVs	$2,397.00	$1,414.00	$1,238.00 (6)	NA
4.Central balanced supply and exhaust with HRV	$2,303.00	$1,320.00	$1,238.00 (6)	NA
5. Base case	$938.00	NA	$878.00	NA

1. Costs are per residential suite
2. All costs are sub-trade costs, ie. exclusive of general contractors mark-up and GST
3. Weighted Canadian average (by Trade and Value) for mechanical and electrical trades
4. Costs are average for Canadian cities
5. Compared with base case
6. Includes motorised damper
7. Indoor unit, sidewall power vented

5.4 Operating Costs

5.4.1 Ventilation and Heating Energy Consumption

The conventional corridor ventilation systems and advanced ventilation systems were modelled assuming conventional and good building envelope configurations, with and without an HRV. The tables below summarise the annual heating energy use and cost for each system in Vancouver, Toronto and Halifax. For additional modelling assumptions, see Appendix C.

Table 12: Comparison of Ventilation and Heating Energy Consumption for Alternative Ventilation Systems, Vancouver Data

	Electric Heating ($0.046/kWh)		Gas Heating at 80% efficiency ($0.0325/kWh)	
	kWh	**$**	**kWh**	**$**
Conventional Envelope and Conventional Corridor Ventilation				
Total Heating	444,800	20,461	556,000	18,070
Ventilation Only	277,166	12,750	346,458	11,260
Conventional Envelope and Advanced Ventilation System				
Total Heating	383,084	17,622	478,855	15,563
Ventilation Only	215,450	9,911	269,313	8,753
Ventilation Only w/ HRV	38,086	1,752	47,608	1,547
Savings	177,364	8,159	221,705	7,205
Good Envelope and Conventional Corridor Ventilation				
Total Heating	219,342	10,090	274,178	8,911
Ventilation Only	218,230	10,039	272,788	8,866
Good Envelope and Advanced Ventilation System				
Total heating	125,656	5,780	157,070	5,105
Ventilation Only	124,544	5,729	155,680	5,060
Ventilation Only w/ HRV	5,838	269	7,298	237
Savings	118,706	5,460	14,8383	4,822

Table 13: Comparison of Ventilation and Heating Energy Consumption for Alternative Ventilation Systems, Toronto Data

	Gas Hydronic Heating at 80% efficiency ($0.0295/kWh)	
	kWh	**$**
Conventional Envelope and Conventional Corridor Ventilation		
Total Heating	718,978	21,210
Ventilation Only	401,015	11,830
Conventional Envelope and Advanced Ventilation System		
Total Heating	643,918	18,996
Ventilation Only	325,955	9,616
Ventilation Only with HRV	63,245	1,866
Savings	262,710	7,750
Good Envelope and Conventional Corridor Ventilation		
Total Heating	411,093	12,127
Ventilation Only	405,185	11,953
Good Envelope and Advanced Ventilation System		
Total heating	282,865	8,345
Ventilation Only	276,958	8,170
Ventilation Only with HRV	25,020	738
Savings	251,938	7,432

Table 14: Comparison of Ventilation and Heating Energy Consumption for Alternative Ventilation Systems, Halifax Data

	Electric Heating ($0.046/kWh)	
	kWh	**$**
Conventional Envelope and Conventional Corridor Ventilation		
Total Heating	531,814	24,463
Ventilation Only	326,650	15,026
Conventional Envelope and Advanced Ventilation System		
Total Heating	466,484	21,458
Ventilation Only	261,320	12,021
Ventilation Only with HRV	47,816	2,200
Savings	213,504	9,821
Good Envelope and Conventional Corridor Ventilation		
Total Heating	296,626	13,645
Ventilation Only	295,236	13,581
Good Envelope and Advanced Ventilation System		
Total heating	192,376	8,849
Ventilation Only	190,986	8,785
Ventilation Only with HRV	6,672	307
Savings	184,314	8,478

5.4.2 Fan Energy

System Efficiencies
Total continuous ventilation rates are 2400 L/s including corridor ventilation. The following motor-fan set efficiencies were used to quantify annual fan energy use:

Conventional central corridor system:		25%
Central corridor system with high-efficiency fans:		38%
Advanced Suite Systems:	corridor fans:	20%
	suite fans:	6%
	suite fans w/ HRV:	13%
Advanced Floor Systems		20%
Advanced Central System		38%

The pressure drop values used (See **Ventilation Fan Input Energy**) were taken from the Assumptions in the Outline Specifications. The annual fan energy use is summarised in the table below.

Table 15: Annual Fan Energy

	Corridor Ventilation	System				Total	
	Input	Input	Input w/ HRV	System Input	System Input w/ HRV	Total Building Input	Total Building Input w/ HRV
System	W	W	W	W	W	W	W
Conventional	700	---	---	---	---	700	---
Conv. w/ High Eff. Fans	250	---	---	---	---	250	---
1 – Suite w/inlet slot	50	1500	---	1500	---	1550	---
2 – Balanced Suite	50	1500	2400	3000	4800	3050	4850
3 – Balanced Floor	---	1400	2600	2800	5200	2800	5250
4 - Central Fans	---	800	1450	1650	2900	1650	2900

5.4.3 Combined Ventilation Heating and Fan Energy Cost Summary

The following tables summarise the total cost of energy required to operate ventilation system fans and heat incoming ventilation air for the conventional system compared to each of the 4 alternative ventilation systems, with and without HRV, in the cities of Vancouver, Toronto, and Halifax.

Table 16: Combined Ventilation Heating and Fan Energy Cost Summary Using Vancouver Data

System	Cost of Fan Energy	Cost of Space Heating	Total Ventilation Cost
Rate cents/kWh	4.6	3.25	
	$ / year	$ / year	$ / year
No HRV			
Conventional Envelope and Ventilation system	$300	$11,250	$11,550
Conventional System with High-Efficiency Fans	$100	$8,750	$8,850
1- Suite w/inlet slot	$600	$5,050	$5,700
2- Balanced Suite	$1,200	$5,050	$6,300
3- Balanced Floor	$1,150	$5,050	$6,200
4- Balanced Central	$650	$5,050	$5,700
With HRV			
2- Balanced Suite	$2,000	$250	$2,450
3- Balanced Floor	$2,100	$250	$2,350
4- Balanced Central	$1,200	$250	$1,400

Table 17: Combined Ventilation Heating and Fan Energy Cost Summary Using Toronto Data

System	Cost of Fan Energy	Cost of Space Heating	Total Ventilation Cost
Rate cents/kWh	7.6	2.9	
	$ / year	$ / year	$ / year
No HRV			
Conventional Envelope and Ventilation system	$500	$11,850	$12,300
Conventional System with High-Efficiency Fans	$150	$11,950	$12,100
1- Suite w/inlet slot	$1,000	$8,200	$9,200
2- Balanced Suite	$2,000	$8,200	$10,200
3- Balanced Floor	$1,900	$8,200	$10,050
4- Balanced Central	$1,100	$8,200	$9,300
With HRV			
2- Balanced Suite	$3,300	$750	$4,050
3- Balanced Floor	$3,500	$750	$4,200
4- Balanced Central	$1,950	$750	$2,700

Table 18: Combined Ventilation Heating and Fan Energy Cost Summary Using Halifax Data

System	Cost of Fan Energy	Cost of Space Heating	Total Ventilation Cost
Rate cents/kWh	8.3	8.3	
	$ / year	$ / year	$ / year
No HRV			
Conventional Envelope and Ventilation system	$550	$15,050	$15,550
Conventional System with High-Efficiency Fans	$200	$12,000	$12,205
1- Suite w/inlet slot	$1,100	$8,800	$9,900
2- Balanced Suite	$2,200	$8,800	$11,000
3- Balanced Floor	$2,050	$8,800	$10,800
4- Balanced Central	$1,200	$8,800	$1,000
w/ HRV			
2- Balanced Suite	$3,500	$300	$3,850
3- Balanced Floor	$3,800	$300	$4,100
4- Balanced Central	$2,100	$300	$2,450

Based on this analysis, the following observations are made:

- For a conventional envelope the ventilation heating load is of the same order as the envelope heating load.
- For the good envelope, there is virtually no envelope heating load since the heat load is offset by internal gains.
- With the good envelope, the 80% heat recovery unit reduces ventilation load by 90%. A large portion of these energy savings are due to the fact that the HRV reduces the ventilation load to the point that internal gains cover a more significant part of the heating season.
- With the conventional systems and no HRV systems, the fan energy is 10% or less than the ventilation heating energy consumption.
- Advanced ventilation systems with HRVs exhibit more than a ten-fold reduction in operating cost over conventional ventilation systems and a five-fold reduction over similar ventilation systems without heat recovery.
- Energy cost savings of as much as $130 per suite per year (eg. Central with HRV, Halifax) are possible from advanced systems with heat recovery.

6 Conclusions

6.1 Problems and Issues with Conventional Ventilation Systems

Current designs for ventilation systems in MURBs do not work well for ensuring adequate indoor air quality. They suffer from a litany of complaints from occupants and building operators and owners about noisy systems, ineffective supply of ventilation air and removal of contaminants, and high-energy consumption.

6.2 Recommendations for Ventilation Rates

An evaluation of ventilation needs for multi-unit residential apartment buildings in Canada was completed. Based on a review of the literature, it was found that ventilation rates required by relevant standards and codes vary significantly, as well as the portion of ventilation expected to be provided by infiltration. It also shows that ventilation rates required to dilute pollutants can be high, source strengths are highly variable and can require dilution ventilation rates that are much higher than required by existing standards, and acceptable exposure limits are not well defined. In the context of balancing the requirements to dilute contaminants, reduce capital and operating costs and avoid low RH levels, ventilation rates in the range of 7.5 L/s per person are recommended. The ASHRAE 62-01 Ventilation Rate Procedure provides the above recommended ventilation rate if the ventilation rates are provided by mechanical systems rather than relying on infiltration through exterior envelopes as assumed in the Standard.

6.3 Performance Parameters to Evaluate Alternative Ventilation Systems

To characterise ventilation performance, the following parameters and targets are proposed. This list is an abridged summary of a more detailed list of parameters, highlighting areas where specific targets were established.

Performance Parameter	Performance Target
Ventilation Performance	Continuous ventilation rate of 100% outdoor air: • One bedroom apartments – 15 L/s • Two bedroom apartments – 22.5 L/s • Three bedroom apartments – 30 L/s Ventilation effectiveness of 1.0 or greater.
Capital and Operating Costs	• Nominal increase in capital cost over conventional systems. • 10 to 20% reduction in ventilation energy consumed.
Maintenance	• All equipment requiring maintenance located in easily accessible locations.

Fire/Smoke Control	• Minimise the need for fire dampers required for vertical ducts through floor to floor separations.
Noise Issues	• 0.6 sone limit on local intermittent use fans.
Comfort	• No cold drafts from air supply.
System Issues	• Simple to use controls. • Simple to maintain. • Slight depressurisation of suites - less than 10 Pa.
Owner/Designer Construction Issues	• Ventilation system should not take up any more floor area than conventional systems.

6.4 Alternative Ventilation Strategies

Four alternative ventilation systems were developed to meet, to the greatest extent possible, performance parameters that overcome the main problems associated with conventional ventilation systems in multi-unit residential buildings. The four systems and their main benefits and drawbacks are summarised below:

System 1 - Passive Vents with Suite Based Mechanical Exhaust

Benefits	• Least cost system, with improved supply of outdoor ventilation air over conventional systems. • Low maintenance. • Least change from current design and construction method.
Drawbacks	• Ventilation performance affected by wind effects. • No tempering of air supply may result in comfort issues in colder climates. • Requires compartmentalisation of suites to work effectively.
Application	• Best used in condominiums or rental suites in temperate locations such as Vancouver, BC.

System 2 - Balanced Individual Suite HRV Units

Benefits	• Excellent ventilation performance when combined with airtight suite design, least affected by wind and stack effects. • Reduced space requirements for vertical corridor ventilation risers.
Drawbacks	• Most expensive initial capital cost. • More fans and HRV units therefore greater maintenance. • Operation and training of occupants required. • Interior space required. • Many external vents required.
Application	• Best used in condominiums where each suite is responsibility for maintenance of their own unit. • Could be used in rental housing if HRV units are located adjacent to hallways with access panels for maintenance.

System 3 - Balanced Floor By Floor System With Heat Recovery

Benefits	• Good ventilation performance with limited negative stack effects,

	when combined with airtight suite design. • Centralised maintenance and control at each floor level.
Drawbacks	• Ventilation performance affected by wind effects. • Space requirement on each floor level for equipment and overhead ducts in hallways.
Application	• Best used in rental applications where centralised control and maintenance is desired. • Could also be used in individual condo applications.

System 4 - Balanced Central System with Heat Recovery

Benefits	• Good ventilation performance when using constant flow controllers at each floor level to limit negative stack effects, combined with airtight suite design. • Lower maintenance. • Centralised maintenance and control.
Drawbacks	• Ventilation performance affected by wind effects. Central systems do not allow for compartmentalisation. • Space requirement for risers and overhead ducts in hallways. • System balancing is difficult and costly.
Application	• Best used in rental applications where central control and maintenance is desired. • Could also be used in individual condo applications.

Based on operating energy analysis, the following observations can be made:

- For a building with an advanced envelope design, the envelope heating load is very low since the heat load is offset by internal gains.
- Advanced ventilation systems with HRV's exhibit more than a ten-fold reduction in operating cost over conventional ventilation systems and a five-fold reduction over similar ventilation systems without heat recovery.
- Energy cost savings of as much as $130 per suite per year (eg. Central with HRV, Halifax) are possible from advanced systems with heat recovery.

7 Recommendations for Future Research

Based on the results of this analysis, the following recommendations for future research are proposed:

Development and Commercialisation of Equipment

11. The following equipment is not readily available and requires further development and commercialisation:
    - A simple packaged apartment ventilation unit designed specifically in terms of flows, durability, power consumption and reliability.
    - Low cost sound traps to reduce noise transfer through ducts between suites.
    - Low cost passive inlet vents, potentially with air tempering capabilities.
    - Pressure-flow control devices to maintain constant flow rates under with variable stack and wind pressures.
    - Low temperature, low flow in duct electric heaters.
    - Low flow low power fans.

Collection of Field Data

12. More field data is required on the performance of both innovative and conventional systems such as air change rates, relative humidity values, ventilation effectiveness, and TVOC levels through all weather conditions.

Cost Information

13. Further research is required to understand the cost implications of the following aspects of alternative ventilation systems:
    - Cost or savings associated with space requirements for equipment and risers.
    - Cost of air sealing required for systems to work effectively.
    - Maintenance costs for all systems.
    - The cost of variable flow systems that can both supply continuous ventilation and supply increasing flowrates on an intermittent basis.

Modelling

14. The focus of this analysis has been on the performance of the ventilation system during the heating season. However, thermal comfort during summer months is a growing issue. Understanding the performance of the alternative ventilation strategies during warm periods is necessary to avoid overheating of apartments. Overheating of corridors is of particular concern.

15. Evaluate one other promising system that was selected for its potential but not evaluated in this study - passive suite intake and mechanical central exhaust, possibly utilising a passive HRV for heat recovery.

Specifications and Standards

16. Develop air sealing recommendations and specifications for exterior walls and interior partitions, including suite doors, to enable systems to work effectively.

Demonstration Projects

17. Construct all four alternative ventilation systems in real buildings and evaluate their as-built performance according to the performance parameters developed in this study.

18. Complete an evaluation of MURBs with alternative ventilation systems to measure performance and identify lessons learned.

Other

19. Further study is required to set stack and wind pressure targets for designers to work with in specifying equipment.

20. Further study is required to set a target for operating hours between maintenance and replacement intervals.

8 References

ASHRAE Standard 62-01 "Ventilation for Acceptable Indoor Air Quality", ASHRAE 2001

ASHRAE Standard 62.2, "Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings" ASHRAE 2002

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Shapiro-Baruch, Ian. 1993. "Evaluation of Ventilation in Multi-family Dwellings" New York State Energy Research and Development Authority, Report 93-5.

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Appendix A - Conservation Co-op - Lessons Learned

The following is a description of the project and documentation of lessons learned by the mechanical designer for the above project.

Building Description:
This is a four storey plus basement, 84 unit co-operative housing project. Suites are mix of one, two, three and four bedroom units.

Typical Floor Ventilation System
Heat pipe roof-top heat recovery units (one per 3 to 4 suites) supply air to the return air of suite combo system air handlers. Air is exhausted continuously from bathrooms and kitchens. Recirculating range hoods with charcoal filters are also provided in the kitchens. Each suite has a boost switch which increases ventilation rates.

A nominal amount of air (60 L/s per floor) is supplied to common corridors and exhausted from recycle rooms.

In the boost mode air is supplied at rates equal to those required by Part 9.32 of the OBC for the "Total Ventilation Capacity"; in the non-boost mode the rates are equal to the required "Principal Exhaust Capacity". Design exhaust quantities were specified at around 110% of the supply.

Success at overcoming Conventional System Weaknesses
We see three principal weaknesses of conventional system:

1. Outdoor air is not consistently and evenly supplied to the living areas in suites leading in poor air quality.
2. Negative pressures are not consistently maintained in each suite leading to odour transfer.
3. High energy costs.

Based on resident feedback and our own (albeit possibly biased view of the engineering), we feel weakness #1 has been largely overcome, item #2 has been somewhat improved and item #3 is a significant improvement. Weaknesses relating to 1 & 2 above are identified in the following section along with some new problems created by this new approach.

System Weaknesses with respect to "Conventional System" problems

1. Cross flow of air is reported between air inlets and exhaust outlets at the individual heat recovery units resulting in some odour transfer. (The inlets and outlets on the units provided are located close together). This could be eliminated or reduced with an alternate equipment configuration. For this project we will be looking at some form of duct extension or baffle.

2. Suite doors are not weather stripped and air flow has been noted between common

hallways and suites. Weather stripping doors would essentially eliminate this air flow path and reduce noise transfer. This measure is being recommended.

Newly Created Problems

1. The biggest problem is reported to be unacceptably high temperatures in summer in the public hallways (and staircases). The hallways have operable windows at both ends of the building but these are not providing sufficient air change to limit overheating. We are looking into the possibility of providing forced ventilation on a floor-by-floor basis by providing a fan at one end of the corridor and an open louvre at the other. The fan would be cycled by a cool action thermostat located in the corridor. Fire doors separating two halves of the building will need to be held open to allow airflow. Door hold-open devices connected to the fire alarm system will be required.

2. The air supplied by the heat recovery units in summer is perceived as being hotter than ambient air aggravating suite over-heating. (Air conditioning is "not allowed" in the building). Air delivery temperature has not been measured (it might be useful to do so) but it is quite likely there is some elevation due to high ambient air temperatures close to the roof surface. We are looking into the possibility of operating the heat recovery units in an exhaust only mode during the summer (It is assumed that outdoor air would be induced through open suite windows). This would also result in reduced power consumption as the supply air fans would be inoperable.

Appendix B: Detailed Description of Alternative Ventilation Strategies

System 1: Passive Vents with Suite Based Mechanical Exhaust

Supply	➢ Linear inlet slots with insect screens above windows at bedrooms and living areas ➢ Inlet slot design to avoid discomfort from cold air spillage and maximise entrainment of room air
Exhaust	➢ Continuous single-speed, low-flow, efficient computer fans (15 L/s to 30 L/s at duct static of 20 Pa) ➢ Exhaust from bathroom(s) with standard grille ➢ Single duct of size approx. 100 mm (4") for 1-bedroom and 125 mm (5") for 3-bedroom (2 m/sec or 400 FPM)
Intermittent High Flow Option	➢ Larger ECM fans (49 L/s to 74 L/s at 20 Pa) to maintain efficiency at continuous flow ➢ Larger intake vents ➢ Larger, longer ducts connected at fan entry: 125 mm (5") kitchen duct and 75 mm (3") bathroom duct joining 150 mm (6") duct at fan for 1-bedroom; additional 75 mm (3") bathroom duct joining to 175 mm (7") duct at fan for 3-bedroom (2 m/sec or 400 FPM) ➢ High flow controls with timed wall switches controlling fan speed

System 2: Balanced Individual Suite HRV Units

Supply and Exhaust	Suite Supply Delivery and Suite Exhaust Extraction ➢ Balanced ventilation unit with continuous single-speed, low-flow, efficient pancake fans (15 L/s to 30 L/s at external duct static of 40 Pa; total with HRV core, 140 Pa) ➢ For heat recovery ventilation, the unit is a highly efficient, single-speed, small capacity HRV ➢ Typical room supply duct delivers 5 L/s of ventilation air resulting in 50 mm (2") branch ducts ➢ Exhaust from bathroom(s) with standard grille ➢ Duct sizes approx. 100 mm (4") for 1-bedroom and 125 mm (5") for 3-bedroom (2 m/sec or 400 FPM)
Intermittent High Flow Option	➢ Larger fans (49 L/s to 74 L/s at 40 Pa; total with HRV core, 140 Pa) to be ECM type to maintain efficiency at continuous flows ➢ Insuite room supply ducts to be 75 mm ➢ Larger, longer ducts connected at fan entry: 125 mm (5") kitchen duct and 75 mm (3") bathroom duct joining 150 mm (6") duct at fan for 1-bedroom; additional 75 mm (3") bathroom duct joining to 175 mm (7") duct at fan for 3-bedroom (2 m/sec or 400 FPM) ➢ High speed controls with timed wall switches controlling fan speed

System 3: Balanced Floor By Floor System With Heat Recovery

Supply and Exhaust	➢ Essentially balanced ventilation unit with continuous single-speed, efficient fans (250 L/s supply incl. 25 L/s for corridor and 225 L/s exhaust, at external duct static of 115 Pa; total with HRV core, 215 Pa) ➢ The ventilation unit is a highly efficient, commercial scale HRV ➢ Typical suite supply duct delivers 5 L/s of ventilation air resulting in 50 mm (2") branch ducts ➢ Exhaust from bathroom(s) with standard grille ➢ Supply and exhaust duct sizes approx. 100 mm (4") for 1-bedroom and 125 mm (5") for 3-bedroom (2 m/sec or 400 FPM) ➢ Supply ducts greater than 100 mm (3-bedroom) need fire dampers ➢ Suite exhaust ducts join at main trunk, which is under negative pressure Maximum size of main trunk is 0.09 m2 or 200 mm by 450 mm (2.5 m/sec or 500 FPM) ➢ Acoustic treatment required to avoid transfer of noise between units – see Assumptions
Intermittent High Flow Option	➢ Single-speed fans from above selected to increase in flow in response to increased supply and exhaust apertures by following fan curves. Design condition is 290 L/s supply and 265 L/s exhaust, at 115 Pa external; total with HRV core, 215 Pa. ➢ Insuite room supply ducts to be 75 mm (3") ➢ Supply duct sizes approx. 150 mm (6") for 1-bedroom and 175 mm (7") for 3-bedroom (2 m/sec or 400 fpm) ➢ Supply ducts greater than 100 mm need fire dampers ➢ Larger, longer ducts connected at trunk: 125 mm (5") kitchen duct and 75 mm (3") bathroom duct joining 150 mm (6") duct at fan for 1-bedroom; additional 75 mm (3') bathroom duct joining to 175 mm (7") duct at fan for 3-bedroom (2 m/sec or 400 FPM) ➢ Maximum size of main trunk is 0.115 m2 or 250 mm by 460 mm (2.5 m/sec or 500 FPM) ➢ High speed control achieved with timed wall switches opening Eneready Whisper Grill exhaust grille

System 4: Balanced Central System with Heat Recovery

Supply and Exhaust	➢ Essentially balanced ventilation unit with continuous single-speed, efficient fans (2500 L/s supply incl. 250 L/s for corridor at duct static of 128 Pa external for supply; total with HRV core, 228 Pa. For 2250 L/s exhaust with dual risers 128 Pa external; total with HRV core, 228 Pa) ➢ The ventilation unit is a highly efficient, larger commercial scale HRV ➢ Typical room supply duct delivers 5 L/s of ventilation air

	resulting in 50 mm (2”) branch ducts ➢ Exhaust from bathroom(s) with standard grille ➢ Supply and exhaust duct sizes approx. 100 mm (4”) for 1-bedroom and 125 mm (5”) for 3-bedroom (2 m/sec or 400 FPM) ➢ Supply ducts greater than 100 mm (3-bedroom) need fire dampers ➢ Suite exhaust ducts join at fire-rated riser, which is under negative pressure ➢ For wind and stack effect each floor has a variable air volume (VAV) damper box, located where floor supply enters horizontal distribution ducts and where exhaust ducts enters risers, to maintain constant flow ➢ Maximum size of each of two main risers (near roof) is 0.3 m2 (4 m/sec or 800 FPM) ➢ Acoustic treatment required to avoid transfer of noise between units – see Assumptions
Intermittent High Flow Option	➢ Single-speed fan from above operates at same speed as flow is controlled at every floor ➢ Insuite room supply ducts to be 75 mm (3”) ➢ Supply duct sizes approx. 150 mm (6”) for 1-bedroom and 175 mm (7”) for 3-bedroom (2 m/sec or 400 fpm) ➢ Larger, longer ducts connected at fan entry: 125 mm (5”) kitchen duct and 75 mm (3”) bathroom duct joining 150 mm (6”) duct at fan for 1-bedroom; additional 75 mm (3’) bathroom duct joining to 175 mm (7”) duct at fan for 3-bedroom (2 m/sec or 400 FPM) ➢ Main supply feed to suite, being greater than 100 mm, needs fire damper ➢ Maximum size of each of two risers (near roof) is 0.3 m2 (4 m/sec or 800 FPM) ➢ High speed control achieved with timed wall switches fully opening motorised damper

Corridor Supply Systems

Systems 1, and 2:

- Corridor air make-up air indirect heating system
- Cooling of corridor air can be added, if desired
- The corridor supply for the building is 250 L/s
- Exhaust is via low amounts of leakage into suites (2.5 L/s per suite)

Systems 3 and 4:

- These two system have dedicated supply to each floor which can also supply corridor air

- Exhaust is the same as with the separate make-up air system

Corridor Heat Recovery Ventilation

- The heat recovery ventilator can be configured for excess supply to reduce cross contamination
- Any rooftop ducting to make heat recovery possible must be insulated to RSI 13.

Appendix C - Additional Energy Modelling Parameters

Wall Areas and R Values

Wall	Area	Window Area	Material		RSI Value	
	m^2	m^2	Conventional	Good	Conv.	Good
SUITES: Zones 1 & 3						
External (North/South)	132	66	Gypsum, 37mm sheath, & siding	Brick, 2x6 stud, 37mm sheath, & siding	2.26	4.45
External (East/West)	23.4		Gypsum, 37mm sheath, & siding	Brick, 2x6 stud, 37mm sheath, & siding	2.26	4.45
Internal partition	Not modelled					
Internal between suite and corridor	132		Gypsum	Gypsum	0.45	0.45
Internal between suites	93.5		Concrete and gypsum	Concrete and gypsum	0.8	0.8
CORRIDOR: Zone 2						
External (East/West)	4.1	2	Gypsum, 37mm sheath, & siding	Brick, 2x6 stud, 37mm sheath, & siding	2.26	4.45
Internal between suite and corridor	132		Gypsum	Gypsum	0.45	0.45

Floors/Ceilings
Floors are 6" concrete slab with 2" hardwood finish, and ceilings are 6" concrete slab with ½" gypsum finish; however, since there will be no heat loss to the suites above or below (since the temperature will be the same) an RSI value of 99 was assigned to both floor and ceiling.

Internal Gains
The following formula was used to estimate the internal gains from lighting, appliances, and occupants in each suite.

Daily Internal Gains = $[(130\ (A)^{1/2} + (200P)]/30.5$,
where,
A = total floor area in m^2
P = average daily number of occupants

Occupancy was assumed to be 1, 2, and 3, for the respective suite sizes. This is a conservative estimate, since one bedroom could hold two people. This formula resulted in internal gains of 70 kWh/day for the suites the North side of the corridor, and the same for the suites on the South side.

The schedule for suite internal gains is as follows:

Hours	% of Total	Load W
12am – 7am	2%	1400
7am – 9am	6%	4200
9am – 6pm	2%	1400
6pm – 7pm	6%	4200
7pm – 9pm	16%	11,200
9pm – 12am	6%	4200
Total	100%	70,000

The internal gains for the corridor were assumed to be 75 watts from 6am to 12am and zero from 12am to 6am, which results in 1.3 kWh/day.

In order to estimate the air leakage between the suites and the corridor through the doors, the following equation from ASHRAE was used.

$A_L = 10\,000\ Q_r\ (s/2DP_r)^{1/2}/\ C_D$,
where, A_L = equivalent or effective air leakage area, cm^2 (88 from Interior Doors section)
Q_r = predicted airflow rate at DP_r, m^3/s
s = air density, kg/m^3 (0.84)
DP_r = reference pressure difference, Pa (4)
C_D = discharge coefficient (1)

This resulted in an airflow rate of 27 L/s.

According to ASHRAE, leakage through walls is approximately 0.9 $L/s.m^2$. This assumption was used to estimate the leakage through the walls separating the suites from the corridor to be 119 L/s on each side.

In ENERPASS this air leakage is modelled as transfer between the suites and the corridor.

Energy Rates

City	Electricity Rate* cents/kWh	Gas cents/kWh
Vancouver	4.6	3.25
Toronto	7.6	2.9
Halifax	8.3	

*Taken from a BC Hydro comparison study of electricity rates for medium power consumers
http://www.bchydro.com/customerservice/rates/business.html

Ventilation Fan Input Energy

System	Corridor Ventilation				System										Total	
	Flow	P. Drop	Eff.	Input	Flow	P. Drop	Eff.	P. Drop w/HRV	Eff.	Input	Input w/ HRV	# of Fans	System Input	System Input w/ HRV	Total Building Input	Total Building Input w/ HRV
	L/s	Pa	%	W	L/s	Pa	%	Pa	%	W	W		W	W	W	W
Conventional	2410	75	0.25	723	---	---	---	---	---	---	---	---	---	---	723	---
Conv. w/ High Eff. Fans	2410	40	0.38	254	---	---	---	---	---	---	---	---	---	---	254	---
1	180	40	0.2	36	2250	40	0.06	---	0.13	1500	---	1	1500	---	1536	---
2	180	40	0.2	36	2250	40	0.06	140	0.13	1500	2423	2	3000	4846	3036	4846
3	---	---	---	---	2430	115	0.2	215	0.2	1397	2612	2	2795	5225	2795	5225
4	---	---	---	---	2430	128	0.38	228	0.38	819	1458	2	1637	2916	1637	2916

Appendix D - Cost Breakdowns - Unit Costs

MURBS Ventilation Study
Unit Bare Costs - Fans and Equipment
LJA ref 2730

Item Description	Application	Materials	Labour	Unit
127mm inline fan,brushes DC motor EBM N26115 series (1)(2)(3)(5)(7)	System #1 bath exhaust	$80.00	$12.75	Each
24 L/s ceiling exhaust, Broan EC50 (4)(5)(7)	Base case 1&2 bed principal exhaust and 3 bed supplementary exhaust	$25.00	$27.00	Each
33 L/s ceiling exhaust, Broan 70 (5)(7)	Base case 3 bed principal exhaust	$50.00	$27.00	Each
Range hood, 200 L/s Broan Allure I (7)	Optional kitchen exhaust	$210.00	$36.00	Each
Heat recovery ventilator (7)(8)	System #2, 1,2 & 3 bed suites	$625.00	$35.00	Each
Interior 262 L/s make up air unit, electric heat, SCR control (7)	Systems 1 & 2 corridor ventilation	$3175.00	$130.00	Each
Interior 247 L/s heat recovery unit (7)	System #3	$2189.85	$61.16	Each
Rooftop 2250 L/s make-up air unit gas heat, atmospheric vented (7)	Base system corridor/make-up	$7,250.00	$675.00	Each
Rooftop 2470 L/s heat recovery unit (7)(9)	System # 4	$17,000.00	$1425.00	Each

Notes:
(1) Square to round transition required at fan, see *Ductwork*
(2) 120v/12v transformers and speed control required, see *Electrical*
(3) Balancing required see *Balancing*
(4) Balance damper and sample balancing required, see *Ductwork* and *Balancing*
(5) Switch required in central location, see *Electrical*
(6) Same size all suites, air flow balanced by speed controllers for fan motors, speed controllers under *Electrical*
(7) See *Electrical* for electrical connection cost
(8) We've used cost from Means, suggested $500 installed cost looks too low given unit to be fitted with EDM, DC motors
(9) We've used a lower figure than suggested based on budget cost from a supplier (Carrier)

Item Description	Application	Materials	Labour	Unit
Straight duct				
Rectangular galvanized steel low pressure	Floor & central systems air distribution (1) 500 to 1000 Lb order 1000 - 2000 Lb order 2000 - 5000 Lb order Over 5000 Lb	 $0.44 $0.38 $0.34 $0.31	 $3.08 $2.97 $2.86 $2.76	 LB LB LB LB
Round Galvanized steel ductwork, 100mm		$0.85	$1.40	LF
Round Galvanized steel ductwork, 125mm	10 suite air distribution	$1.08	$1.58	LF
Round Galvanized steel ductwork, 175mm	Range exhaust	$1.46	$2.11	LF

Fittings & Accessories				
100mm elbow	in-suite air distribution	$1.79	$8.45	Each
125mm elbow	in-suite air distribution	$2.30	$9.70	Each
175mm elbow	in-suite air distribution	$3.31	$18.05	Each
100/125 diam mm of round to rectangular transition [3]	wall box and high efficiency fans	$10.58	$15.80	Each
175mm round to rectangle transition	kitchen hood	$5.60	$12.65	Each
125 mm Tee-fitting	in-suite air distribution	$7.29	$14.60	Each
100 mm Tee-fitting	in-suite air distribution	$6.91	$12.65	Each
150 X150 egg crate grille	Ceiling exhaust, bathrooms	$13.45	$10.80	Each
300 x 250 sidewall supply air register	Base case corridor supply	$31.00	$15.60	Each

150 X 100 double deflection sidewall supply air register	Suite & System 1 & 2corridor air supply	$19.50	$11.70	Each
Aluminium Brick vent with wall box	Suite exhaust	$60	$20.15	Each
Fixed aluminium blade weather louvre 241 L/s	Building exhaust & OA, System # 3	$28.00	$10.50	Sq.Ft.
Passive air inlet	System # 1 air inlet	$99.17	$21.76	Each
300 X 300 Duct Access door		$17.55	$28.00	Each
Acoustically insulated sound trap	Systems 3 & 4 (4)	$160.00	$10.00	Each
150 x 150 Fire Damper		$19.85	$11.70	Each
300 x 250 Fire Damper		$20.50	$13.55	Each
250 X 250 Fire dampers		$19.75	$12.75	Each
100 mm diam balancing dampers		$0.52	$12.60	Each
125 mm diam balancing dampers		$0.54	$12.75	Each
100 mm diam take off dampers Round branch off rectangular trunk		$1.32	$10.10	Each
125 mm diam take off dampers Round branch off rectangular trunk		$1.42	$10.80	Each
Motorised damper (2)	Advanced ventilation system optional kitchen exhaust	$200.20	$54.75	Each

Notes:
(1) Allowance for duct fittings in unit price
(2) Electrical hook-up required see *Electrical*
(3) Same price used for 100 and 125 ι duct, custom fabrication for high efficiency fan and wall boxes.
(4) Nominal 175 x 175 mm acoustically insulated z duct, custom fabrication

MURBS Ventilation Study
Unit Bare Costs - Insulation
LJA ref 2730

Item Description	Application	Materials	Labour	Unit
25mm Acoustic insulation	Rectangular ductwork	$1.29	$3.21	SF
50mm Flexible fiberglass thermal insulation, KRF & canvas jacket	Rectangular ductwork: exposed	$3.11	$6.43	SF
50mm Flexible fiberglass thermal insulation, KRF jacket	Rectangular ductwork: concealed	$0.89	$1.61	SF
25 mm Thick insulation sleeve for 100 mm duct	Round Ductwork	$1.00	$1.01	LF
25 mm thick insulation sleeve for 175 mm duct		$1.74	$1.77	LF
Exterior weather proof jacket	Exterior ductwork, System # 4	$3.17	$4.82	SF

MURBS Ventilation Study
Unit Bare Costs - Air Balancing
LJA ref 2730

Item Description	Application	Materials	Labour	Unit
Supply & exhaust register & diffusers		NA	$35.82	Each
Ceiling fan		NA	$50.74	Each
HRV suite units		NA	$63.43	Each
HRV floor units		NA	$103.86	Each
HRU central unit		NA	$370.00	Each
Make up air unit		NA	$268.63	Each
Branch air flow		NA	$34.62	Each

MURBS Ventilation Study
Unit Bare Costs - Plumbing
LJA ref 2730

Item Description	Application	Materials	Labour	Unit
NPS 1 1/4Schedule 40 Screwed Piping (1)	Gas Piping	$1.40	$4.36	LF
NPS 3/4 Type M tubing	Condensate drains	$1.68	$3.69	LF
NPS 1 1/4 DWV tubing	Condensate drains	$2.88	$4.79	LF
NPS 1 1/4 Reducing T's	Condensate drains	$6.85	$2.90	Each
NPS 1 1/4 90E Elbows	Condensate drains	$3.03	$19.15	Each

(1) Actual size would vary with location

MURBS Ventilation Study
Unit Bare Costs - Electrical
LJA ref 2730

Item Description	Application	Materials	Labour	Unit
120v/15A toggle switch (4)(6)	Suite fan or HRVcontrol	$17.05	$19.85	Each
Exhaust fan power connection (4)(6)	Bathroom & range hood exhaust	$15.65	$14.20	Each
Motorized damper hook up (1)(4)(6)	Advanced vent systems kitchen exhaust optional	$15.65	$14.20	Each
Suite HRV power connection (2)(4)(6)(7)	System # 2 HRU	$63.75	$52.55	Each
Floor HRV power connection (5)	System # 3 HRU	$28.65	$31.65	Each
Central HRU power connection (5)	System # 4 HRU	$203.78	$262.80	Each
Electrical MUA with power connection (5)	Systems # 1 & 2 corridor ventilation unit	$250.00	$259.00	Each
Gas MUA with power connection (5)	Base case corridor supply	$203.78	$262.80	Each
High efficiency exhaust fan power connection (3)(6)	System # 1, bath exhausts	$46.35	$40.75	Each

Notes:
(1) Includes interlocking to open when hood started
(2) No electric heat included **@@ may be required some locations @@**
(3) Includes 120/24 V transformer and speed control switch for balancing
(4) 20 ft. average runs, # 14/2 wiring
(5) EMT & wire
(6) Bx cable
(7) Assumes DC motors; 120/24V transformer and two speed control switches for balancing costed, ideally this would be part of the HRV
requiring only a 120 V hook-up.

MURBS Ventilation Study
Unit Bare Costs - Builders Work
LJA ref 2730

Item Description	Application	Materials	Labour	Unit
150 X 150 Drywall bulkhead (½" drywall on steel channel) (1)	Duct enclosure	$2.65	$8.81	LF
Drywall dropped ceiling (½" drywall on steel channel) (1)	Duct / equipment enclosure	$0.62	$1.11	SF
Suspended & bar ceiling	Duct/equipment enclosure	$1.06	$0.86	SF
525 X 500 mm fire rated shaft, drywall & steel studs (1)(2)	Base case corridor supply air duct enclosure	$8.15	$18.54	LF
400 X 300 mm fire rated shaft, drywall & steel studs (1)(2)	Systems # 1& 2 corridor supply air duct enclosure	$6.66	$15.39	LF
300 x 300 mm Drywall access door	Damper and fan access	$15.77	$7.02	Each
450 x 330 mm fire rated shaft, drywall & steel studs (1)(2)	System # 4 Supply and exhaust duct enclosures	$6.99	$16.11	Each

Notes:
(1) Excludes finishing, assumes no incremental costs
(2) Dimensions are clear inside shaft

Appendix E - Cost Breakdowns - Detailed Costing By System

1) System 1

LJA REFERENCE: 2730

MULTIPLIERS

DESCRIPTION	UNIT COST Material	Labour
P.S.T.	7 %	0 %
Overhead	0 %	45 %
Profit	10 %	10 %
Average Canadian Cities (3)	4 %	-14 %
Sub Total	21 %	41 %

REF	DESCRIPTION	UNIT COST Hrs.	Material	Labour	QUANTITY	BARE COSTS Hrs.	Materials
	High efficiency fan		$80.00	$12.75	100	0	$8,000.00
	Brick vent and wall box		$60.00	$20.15	100	0	$6,000.00
	Passive ventilators		$99.17	$21.76	300	0	$29,751.00
	Ceiling access door (to fan)		$15.77	$7.02	100	0	$1,577.00
	Drywall bulkhead		$2.65	$8.81	1940	0	$5,141.00
	Insulation sleeves (4)		$1.00	$1.77	600	0	$600.00
	100 mm diam duct		$0.85	$1.40	1850	0	$1,572.50
	125 mm diam duct		$1.08	$1.58	810	0	$874.80
	Exhaust grills		$13.45	$10.80	130	0	$1,748.50
	Square to round transition		$10.58	$15.80	300	0	$3,174.00
	100 mm elbows		$1.79	$8.45	180	0	$322.20
	125 mm elbows		$2.30	$9.70	90	0	$207.00
	125 mm T-fittings		$6.91	$14.60	30	0	$207.30
	Fan hook up (DC motor)		$46.35	$40.75	100	0	$4,635.00
	Fan control switch		$17.05	$19.85	100	0	$1,705.00
	Suite exhaust fan balancing (5)			$73.58	100	0	$0.00
Sub Total				BARE		0	$65,515.30
				ACTUAL		0	$79,273.51
				OVERALL TOTAL COST			$156,734.97

Notes:

1. Cost based primarily on RS Means cost data 2002
2. All costs are sub-trade costs, ie exclusive of the general contractor mark up, and GST
3. Weighted average (by trade $ value) for mechanical and electrical trades
4. To 6 Ft back from exterior wall
5. Using speed controller
6. See separate sheet for common corridor system

2) System 2 (4)

LJA REFERENCE: 2730

MULTIPLIERS

DESCRIPTION	UNIT COST Material	Labour
P.S.T.	7 %	0 %
Overhead	0 %	45 %
Profit	10 %	10 %
Average Canadian Cities (3)	4 %	-14 %
Sub Total	21 %	41 %

REF	DESCRIPTION	UNIT COST Hrs.	Material	Labour	QUANTITY	BARE COSTS Hrs.	Materials
	Heat recovery ventilators (6)		$625.00	$35.00	100	0	$62,500.00
	Brick vent and wall box		$60.00	$20.15	200	0	$12,000.00
	Drywall bulkhead		$2.65	$8.81	4980	0	$13,197.00
	Insulation sleeves		$1.00	$1.01	2280	0	$2,280.00
	100 mm diam duct		$0.85	$1.40	6020	0	$5,117.00
	125 mm diam duct		$1.08	$1.58	3510	0	$3,790.80
	Exhaust grills		$13.45	$10.80	130	0	$1,748.50
	Supply air registers		$19.50	$11.70	300	0	$5,850.00
	Square to round transition		$10.58	$15.80	200	0	$2,116.00
	100 mm diam elbows		$1.79	$8.45	570	0	$1,020.30
	125 mm diam elbows		$2.30	$9.70	300	0	$690.00
	100 mm T-fittings		$6.91	$12.65	110	0	$760.10
	125 mm T-fittings		$7.29	$14.60	120	0	$874.80
	HRV hook-up (5)		$63.75	$52.55	100	0	$6,375.00
	HRV control switch		$17.05	$19.85	100	0	$1,705.00
	Suite HRV balancing			$63.43	100	0	$0.00
	Supply register balancing			$35.82	300	0	$0.00
	3/4" copper tube		$1.68	$2.69	300	0	$504.00
	1 1/4" copper tube		$2.88	$4.79	700	0	$2,016.00
	1 1/4" reducing T's		$6.85	$29.00	100	0	$685.00
	1 1/4" 90 deg elbows		$3.03	$19.15	4	0	$12.12
Sub Total				BARE		0	$123,241.62
				ACTUAL		0	$149,122.36
				OVERALL TOTAL COST			$315,629.26

Notes:

1. Cost based primarily on RS Means cost data 2002
2. All costs are sub-trade costs, ie exclusive of the general contractor mark up, and GST
3. Weighted average (by trade $ value) for mechanical and electrical trades
4. See separate sheet for common corridor system
5. Assumes DC motors
6. Excludes cost of re-heat which may be required in some locations

3) Systems 1 & 2 Common Corridor Systems

LJA REFERENCE: 2730

MULTIPLIERS

DESCRIPTION	UNIT COST Material	Labour
P.S.T.	7 %	0 %
Overhead	0 %	45 %
Profit	10 %	10 %
Average Canadian Cities (3)	4 %	-14 %
Sub Total	21 %	41 %

REF	DESCRIPTION	UNIT COST Hrs.	Material	Labour	QUANTITY	BARE COSTS Hrs.	Materials
	Electric make-up air unit		$3,175.00	$130.00	1	0	$3,175.00
	Ductwork (galvanized steel rectangular)		$0.44	$3.08	308	0	$135.52
	Outdoor air louvre		$28.00	$10.50	2	0	$56.00
	Thermal insulation (4)		$3.11	$6.43	20	0	$62.20
	Supply air registers		$19.50	$11.70	10	0	$195.00
	Fire dampers		$19.85	$11.70	10	0	$198.50
	Fire rated shaft		$6.66	$15.39	85	0	$566.10
	Balancing MUA			$268.63	1	0	$0.00
	Balancing registers			$35.82	10	0	$0.00
	Electric hook-up		$250.00	$259.00	1	0	$250.00
Sub Total				BARE		0	$4,638.32
				ACTUAL		0	$5,612.37
				OVERALL TOTAL COST			$10,767.64

Notes:

1. Cost based primarily on RS Means cost data 2002
2. All costs are sub-trade costs, ie exclusive of the general contractor mark up, and GST
3. Weighted average (by trade $ value) for mechanical and electrical trades
4. On air intake duct from louvre to MUA unit

4) System 3 LJA REFERENCE: 2730

MULTIPLIERS

DESCRIPTION	UNIT COST	
	Material	Labour
P.S.T.	7 %	0 %
Overhead	0 %	45 %
Profit	10 %	10 %
Average Canadian Cities (3)	4 %	-14 %
Sub Total	21 %	41 %

REF	DESCRIPTION	UNIT COST			QUANTITY	BARE COSTS	
		Hrs.	Material	Labour		Hrs.	Materials
	Supply air registers		$19.50	$11.70	310	0	$6,045.00
	Exhaust grills		$13.45	$10.80	130	0	$1,748.50
	247 L/S HRV (5)		$2,189.85	$61.16	10	0	$21,898.50
	Weather louvres		$28.00	$10.50	4	0	$112.00
	Ductwork (galvanized steel rectangular)		$0.31	$2.76	6990	0	$2,166.90
	Thermal Insulation		$3.11	$6.43	83	0	$258.13
	T-bar ceiling (4)		$1.06	$0.86	5423	0	$5,748.38
	Acoustic insulation		$1.29	$3.21	83	0	$107.07
	3/4" copper tube		$1.68	$2.69	30	0	$50.40
	1 1/4" copper tube		$2.98	$4.79	100	0	$298.00
	1 1/4" reducing T's		$6.85	$29.00	10	0	$68.50
	1 1/4" 90 deg elbows		$3.03	$19.15	2	0	$6.06
	Duct sound traps		$160.00	$10.00	200	0	$32,000.00
	Fire dampers (150 x 150)		$19.85	$11.70	200	0	$3,970.00
	Duct access doors		$17.55	$28.00	200	0	$3,510.00
	HRV balancing			$103.86	10	0	$0.00
	Supply register and exhaust grill balancing			$35.82	440	0	$0.00
	Branch duct balancing			$34.62	200	0	$0.00
	HRV electrical hook-up		$63.75	$52.55	10	0	$637.50
	Drywall bulkhead		$2.65	$8.81	1690	0	$4,478.50
	Fire dampers (250x250)		$19.75	$12.75	20	0	$395.00
	100 mm dia duct		$0.85	$1.40	2690	0	$2,286.50
	125 mm dia duct		$1.08	$1.58	1200	0	$1,296.00
	100 mm dia elbows		$1.79	$8.45	30	0	$53.70
	100 mm dia T's		$6.91	$12.65	100	0	$691.00
	125 mm dia T's		$7.29	$14.60	90	0	$656.10
	100 mm balancing dampers		$0.52	$12.60	140	0	$72.80
	125 mm balancing dampers		$0.54	$12.75	60	0	$32.40
	100 mm dia take off		$1.32	$10.10	140	0	$184.80
	125 mm dia take off		$1.42	$10.80	60	0	$85.20
Sub Total				BARE		0	$88,856.94
				ACTUAL		0	$107,516.90
				OVERALL TOTAL COST			$239,700.45

Notes: 1. Cost based primarily on RS Means cost data 2002

2. All costs are sub-trade costs, ie exclusive of the general contractor mark up, and GST

3. Weighted average (by trade $ value) for mechanical and electrical trades

4. Incremental cost for 7 floors; lower upper and mid often used for services distribution

5. Excludes cost of re-heat which may be required in some locations. Mario's suggest cost used, consistant with Means

5) System 4

LJA REFERENCE: 2730

MULTIPLIERS

DESCRIPTION	UNIT COST Material	Labour
P.S.T.	7 %	0 %
Overhead	0 %	45 %
Profit	10 %	10 %
Average Canadian Cities (3)	4 %	-14 %
Sub Total	21 %	41 %

REF	DESCRIPTION	UNIT COST Hrs.	Material	Labour	QUANTITY	BARE COSTS Hrs.	Materials
	Supply air registers		$19.50	$11.70	310	0	$6,045.00
	Exhaust grills		$13.45	$10.80	130	0	$1,748.50
	2470 L/s HRU		$17,000.00	$1,425.00	1	0	$17,000.00
	Ductwork (galvanized steel rectangular)		$0.34	$2.86	3068	0	$1,043.12
	T bar ceiling (4)		$1.06	$0.86	5423	0	$5,748.38
	Duct sound traps (6)		$160.00	$10.00	100	0	$16,000.00
	Fire dampers (150x150)		$19.85	$11.70	110	0	$2,183.50
	Duct access doors		$17.55	$28.00	110	0	$1,930.50
	HRU balancing			$370.00	1	0	$0.00
	Supply register and exhaust grill balancing			$35.82	440	0	$0.00
	Branch duct air balancing			$34.62	200	0	$0.00
	HRU electrical hook-up		$203.78	$262.80	1	0	$203.78
	Drywall bulkhead		$2.65	$8.81	1690	0	$4,478.50
	Fire rated Shaft		$6.99	$16.11	255	0	$1,782.45
	Duct thermal insulation (5)		$0.89	$1.61	1554	0	$1,383.06
	Duct acoustic insulation		$1.29	$3.21	710	0	$915.90
	Duct weather jacket		$3.17	$4.82	843	0	$2,672.31
	100 mm diam duct		$0.85	$1.40	4820	0	$4,097.00
	125 mm diam duct		$1.08	$1.58	2760	0	$2,980.80
	100 mm diam elbows		$1.79	$8.45	450	0	$805.50
	125 mm diam elbows		$2.30	$9.70	240	0	$552.00
	100 mm T's		$6.91	$12.65	40	0	$276.40
	125 mm T's		$7.29	$14.60	120	0	$874.80
	100 mm take offs		$1.32	$10.10	150	0	$198.00
	125 mm take offs		$1.42	$10.80	60	0	$85.20
	100 mm balance dampers		$0.52	$12.60	140	0	$72.80
	125 mm balance dampers		$0.54	$12.75	60	0	$32.40
Sub Total				BARE		0	$73,109.90
				ACTUAL		0	$88,462.98
				OVERALL TOTAL COST			$230,322.25

Notes:

1. Cost based primarily on RS Means cost data 2002
2. All costs are sub-trade costs, ie exclusive of the general contractor mark up, and GST
3. Weighted average (by trade $ value) for mechanical and electrical trades
4. Incremental cost for 7 floors, lower upper and mid often used for service distribution
5. Two 50 mm layers (exterior duct)
6. On supply air only

6) Base Case Suites Exhaust

LJA REFERENCE:
2730

MULTIPLIERS

DESCRIPTION	UNIT COST	
	Material	Labour
P.S.T.	7 %	0 %
Overhead	0 %	45 %
Profit	10 %	10 %
Average Canadian Cities (3)	4 %	-14 %
Sub Total	21 %	41 %

REF	DESCRIPTION	UNIT COST			QUANTITY	BARE COSTS	
		Hrs.	Material	Labour		Hrs.	Materials
	24 L/S ceiling fan		$25.00	$27.00	100	0	$2,500.00
	33 L/S ceiling fan		$50.00	$27.00	30	0	$1,500.00
	Brick vent and wall box		$60.00	$20.15	100	0	$6,000.00
	Drywall bulkhead		$2.65	$8.81	1922	0	$5,093.30
	Insulation sleeve (4)		$1.00	$1.01	780	0	$780.00
	100 mm diam duct		$0.85	$1.40	2578	0	$2,191.30
	100 mm elbows		$1.79	$8.45	260	0	$465.40
	Square to round transitions		$10.58	$15.80	130	0	$1,375.40
	Fan hook-up		$15.65	$14.20	130	0	$2,034.50
	Fan control switch		$17.05	$19.85	130	0	$2,216.50
Sub Total				BARE		0	$24,156.40
				ACTUAL		0	$29,229.24
				OVERALL TOTAL COST			$79,329.82

Notes:

1. Cost based primarily on RS Means cost data 2002
2. All costs are sub-trade costs, ie exclusive of the general contractor mark up, and GST
3. Weighted average (by trade $ value) for mechanical and electrical trades
4. To 6' back from exterior wall
5. See separate sheet for corridory supply air system
6. Excludes kitchen exhausts, see separate sheet for kitchen exhausts

7) Base case, corridor air supply

LJA REFERENCE: 2730

MULTIPLIERS

DESCRIPTION	UNIT COST	
	Material	Labour
P.S.T.	7 %	0 %
Overhead	0 %	45 %
Profit	10 %	10 %
Average Canadian Cities (3)	4 %	-14 %
Sub Total	21 %	41 %

REF	DESCRIPTION	UNIT COST			QUANTITY	BARE COSTS	
		Hrs.	Material	Labour		Hrs.	Materials
	Gas fired MUA unit (4)		$7,250.00	$675.00	1	0	$7,250.00
	Ductwork		$0.44	$3.08	565	0	$248.60
	Supply air registers		$31.00	$15.60	10	0	$310.00
	Fire dampers		$20.50	$13.55	10	0	$205.00
	Fire rated shaft		$8.15	$18.54	85	0	$692.75
	Balancing MUA			$268.63	1	0	$0.00
	Balancing registers			$35.82	10	0	$0.00
	Electric hook-up		$203.78	$262.80	1	0	$203.78
	Gas piping (4)(5)		$1.40	$4.36	120	0	$168.00
Sub Total				BARE		0	$9,078.13
				ACTUAL		0	$10,984.54
				OVERALL TOTAL COST			$19,015.09

Notes:

1. Cost based primarily on RS Means cost data 2002
2. All costs are sub-trade costs, ie exclusive of the general contractor mark up, and GST
3. Weighted average (by trade $ value) for mechanical and electrical trades
4. Roof top unit assumed
5. Lineal foot cost includes allowance for fittings

8) Optional Kitchen Exhaust

LJA REFERENCE: 2730

MULTIPLIERS

DESCRIPTION	UNIT COST Material	Labour
P.S.T.	7 %	0 %
Overhead	0 %	45 %
Profit	10 %	10 %
Average Canadian Cities (3)	4 %	-14 %
Sub Total	21 %	41 %

REF	DESCRIPTION	UNIT COST Hrs.	Material	Labour	QUANTITY	BARE COSTS Hrs.	Materials
	Range hood		$210.00	$36.00	100	0	$21,000.00
	Brick vent and wall box		$60.00	$20.15	100	0	$6,000.00
	Drywall bulkhead		$2.65	$8.81	1575	0	$4,173.75
	Insulation sleeve (4)		$1.74	$1.77	600	0	$1,044.00
	175 mm diam duct		$1.46	$2.11	2230	0	$3,255.80
	Square to round transition		$5.60	$12.65	100	0	$560.00
	175 mm elbow		$3.31	$18.05	100	0	$331.00
	Range hood hook-up		$15.65	$14.20	100	0	$1,565.00
						0	$0.00
						0	$0.00
						0	$0.00
Sub Total				BARE		0	$37,929.55
				ACTUAL		0	$45,894.76
				OVERALL TOTAL COST			$87,839.51

Notes:

1. Cost based primarily on RS Means cost data 2002
2. All costs are sub-trade costs, ie exclusive of the general contractor mark up, and GST
3. Weighted average (by trade $ value) for mechanical and electrical trades
4. To 6' back from exterior wall
5. Incremental cost of providing motorised damper $360 (includes electrical hook-up) per suite