RESEARCH REPORT

Field Investigations of Indoor Environment and Energy Usage in Mid-Rise Residential Buildings

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Final Report

FIELD INVESTIGATIONS OF INDOOR ENVIRONMENT AND ENERGY USAGE IN MID-RISE RESIDENTIAL BUILDINGS

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EXECUTIVE SUMMARY

Over the last three decades, the growth in multi-unit residential building stock is phenomenal. There are about 3.2 million residential units provided by multi-unit residential buildings accounting for about 31% of the total housing dwellings in Canada. Despite the size and importance of this segment of the housing stock, little information is available with regard to general performance, occupant responses with regard to indoor air quality and, above all, energy efficiency.

The focus of the present study was to evaluate the thermal and indoor environment performance of mid-rise buildings, more specifically three to five storey apartments. Pertinent questions which were evaluated during the course of work include the following:

- What is the airtightness of mid-rise apartment buildings which have the air-barrier system installed as per the 1990 Code requirements?
- What is the status of the installed capacity of ventilation systems and how are these systems performing?
- How do occupants perceive indoor air quality in mid-rise apartment buildings and what are the trends in common indoor environment parameters?
- How is the building performing based on the thermal and energy efficiency criteria?
- How does the mid-rise residential segment compare to high-rise and single family housing?

The research plan included the development of test and evaluation protocols for indoor environment parameters, energy consumption patterns and ventilation system performance parameters for mid-rise buildings. As part of the field work, a total of eight buildings were chosen for detailed evaluation; four buildings in Vancouver, two in Ottawa and two in Toronto. All the buildings were built in the last five years (1990 or later) to reflect current design and construction practices. The detailed evaluation of eight mid-rise residential buildings showed the following trends:

Air Leakage and Ventilation Performance:

- The airtightness of the building shell ranged from 2.23 L/s.m^2 to 3.60 L/s.m^2 at 75 Pa pressure difference. The measured values of airtightness for various buildings are significantly higher than what can be expected in buildings with carefully installed and commissioned air barrier systems. The airtightness from current practice should range from as low as 0.3 to 1.7 L/s.m^2 at 75 Pa pressure difference as per opinions of some participants of Building Science Insight seminars conducted by National Research Council of Canada.
- The air change rate tests using the passive sampling devices showed that the mechanical ventilation accounted for 0.1 to 0.67 air changes per hour in occupied suites. In several buildings, the estimated mechanical ventilation rate was substantially lower than the required rate of 0.30 air changes per hour as per CSA Standard F-326.
- All except one Ottawa building have a corridor make-up air ventilation system. The installed capacity of these systems met or exceeded the ventilation requirements set by ASHRAE Standard 62-1989 which was about 20 to 80 L/s per suite. Measured air flow rates for the corridor ventilation system ranged from 55% to 99% of the rated installed ventilation capacity in the building.
- The corridor ventilation air entering the suite through the door was negligible in five of the eight buildings due to weatherstripping of the suite/corridor entry door. Ventilation air entering the suite through the corridor in the other three buildings ranged from 13 to 27 L/s. The supply of ventilation air in suites falls short off the requirements set by CSA F-326 which ranged from 20 to 35 L/s per suite.

- All suites had bathroom exhaust and kitchen exhaust fans. In all buildings, the installed capacity of bathroom and kitchen exhaust fans met the requirements set by CSA F-326. However, the measured air flow rates of kitchen and bathroom exhaust fans showed that most bathroom fans exhausted 30% to 85% of their rated capacity. The performance of kitchen fans was slightly better than bathroom fans but not acceptable. Kitchen fans exhausted 50% to 90% of their rated capacity.
- Occupant surveys showed that about 82% occupants regularly used kitchen exhaust fans while 41% of occupants regularly used bathroom exhaust fans.
- From the above observations, we found that mid-rise residential buildings had the necessary ventilation and exhaust equipment installed to meet the code requirements. However, the performance evaluation showed that these exhaust and ventilation systems did not function to the required level and generated significantly low air movement in the building. Make-up air system provided the fresh air in corridors which eventually dumped to outside due to a lack of proper transfer mechanism between the corridor and the suites. The under-performance of ventilation systems also seem to cause high levels of relative humidity, high levels of carbon dioxide, window condensation and mold growth in several buildings.

Indoor Environment:

- Occupant surveys reported that about 16% of tenants feel that they suffer from health problems due to poor indoor air quality in some buildings. About 39% of tenants complained about window condensation; 14% of occupants complained about mold growth in their suites; and only 57% of occupants felt that the quality of indoor air was acceptable in their buildings.
- In several buildings, relative humidity and carbon dioxide levels exceeded the normal acceptable limits set by Health Canada Guidelines. These buildings also had insufficient ventilation and air movement in the suites. Occupant complaints are also high. The occupant complaints in these building seem to be due to improper and/or lack of adequate ventilation and air distribution.
- The emissions of formaldehyde and VOCs from building materials were substantially below acceptable limits in all buildings.
- The field survey also showed that the electromagnetic fields were much lower than 8 milligauss in all test units. Ontario Hydro recommends a level up to 20 milligauss near the equipment and about 8 milligauss at 0.3 m away from the source.
- Lighting levels in common areas of mid-rise apartment buildings generally met or exceeded the requirements set by good practices and Code requirements.

Energy Use in Buildings:

- The purchased energy in mid-rise buildings ranged from 146 to 263 kWh/m^2 of floor area per year. The annual energy cost ranged from \$6.76/m^2 to \$20.05/m^2 with an average of about \$10/m^2. The utility bill for each suite ranged from \$461 to \$1,683 per year. The average utility bill per suite was about \$746 per year based on costing data available for the year 1994.
- The analysis of heat gains during the heating season showed that solar gains contributed about 10% (11.5 ± 3.1 kWh/m^2) of space heating requirements while the internal gains accounted for 19% (21.4 ± 4.7 kWh/m^2) of the space heating needs. The average purchased space heating energy requirements was about 112.8 ± 23.6 kWh/m^2.
- The heat loss components during the heating season were as follows: walls accounted for 16%; roof at 7%; below grade losses at 8%; windows and doors at 30%; air leakage at 23% and the mechanical ventilation at 16% of total heat losses.

- Energy balance analysis showed that for the eight test buildings the energy use was as follows:
  - purchased energy ranged from 146 to 263 kWh/m^2 and average of 184.6 ± 40.7 kWh/m^2.
  - space heating accounted for 43.5% ± 8.8%;
  - domestic hot water use accounted for 25.3% ± 2.6%;
  - lighting accounted for 14.8% ± 4.8%; and
  - miscellaneous energy use (suite appliances, air-conditioning and other equipment) accounted for 15.8% ± 5.1%.
- Comparison showed that the mean value of the energy consumption for a high-rise and mid-rise building is almost the same. Compared to a single family housing, the mid-rise residential units had about 10% less energy consumption per unit area despite the fact that mid-rise units had significantly less exposed surface area than single-family houses.

Overall, the field survey and energy analyses provided significant new insights into the mid-rise apartment buildings. These findings should help in future design, construction and commissioning of apartment buildings. Further work is needed to develop design criteria, construction details, effective ventilation systems, quality control and commissioning procedures and, above all, a comprehensive guidelines for interweaving occupant comfort and energy efficiency in mid-rise residential buildings.

RÉSUMÉ

Au cours des trente dernières années, le parc des logements collectifs a connu une croissance phénoménale. Les immeubles résidentiels procurent aux Canadiens quelque 3,2 millions de logements, soit 31 % de l'ensemble des logements au pays. En dépit de la taille et de l'importance de ce segment du parc de logements, on en sait peu sur la performance générale de ces habitations, sur les opinions de leurs occupants au sujet de la qualité de l'air intérieur et, surtout, sur leur efficacité énergétique.

La présente étude avait pour but d'évaluer la performance de bâtiments de hauteur moyenne comptant de trois à cinq étages en regard du chauffage et du milieu intérieur. L'évaluation a été faite à partir des questions énoncées ci-dessous :

- Dans quelle mesure les immeubles d'appartements de moyenne hauteur sont-ils étanches à l'air lorsque leurs pare-air ont été mis en oeuvre conformément aux exigences du Code de 1990?
- Quelle est la tenue en service des installations de ventilation et comment ces systèmes se comportent-ils?
- Comment les occupants perçoivent-ils la qualité de l'air intérieur dans les immeubles d'appartements de moyenne hauteur et quelles sont les tendances relatives aux paramètres communs du milieu intérieur?
- Quelle est la performance de l'immeuble par rapport aux critères d'efficacité thermique et énergétique?
- À quel niveau se situe le segment des immeubles de moyenne hauteur comparativement aux tours d'habitation et aux maisons individuelles?

Le plan de recherche prévoyait l'élaboration de protocoles d'essai et d'évaluation pour le milieu intérieur, les habitudes de consommation d'énergie et la performance des installations de ventilation des immeubles de moyenne hauteur. Sur le terrain, huit bâtiments ont été sélectionnés pour subir une évaluation détaillée, soit quatre bâtiments à Vancouver, deux à Ottawa et deux autres à Toronto Tous les bâtiments ont été construits au cours des cinq dernières années (à partir de 1990), donc selon les méthodes actuelles de conception et de construction. L'évaluation détaillée de ces huit immeubles résidentiels de moyenne hauteur a fait ressortir les tendances suivantes :

Fuites d'air et performance de la ventilation

- L'étanchéité à l'air de l'enveloppe des bâtiments varie de 2,23 L/s.m² à 3,60 L/s.m² à une différence de pression de 75 Pa. Les valeurs mesurées de l'étanchéité à l'air de divers immeubles sont de beaucoup supérieures à ce qu'elles devraient être pour des bâtiments dont les pare-air ont été mis en oeuvre et mis en service avec le plus grand soin. Les méthodes actuelles devraient permettre d'atteindre une étanchéité à l'air dans un éventail compris entre 0,3 et 1,7 L/s.m² à une différence de pression de 75 Pa. C'est du moins l'avis de certains participants aux séminaires *Regard sur la science du bâtiment* présentés par le Conseil national de recherches du Canada.
- Les essais visant à déterminer le taux de renouvellement d'air, effectués au moyen d'appareils d'échantillonnage passifs, ont montré que la ventilation mécanique permettait d'obtenir des taux de 0,1 à 0,67 renouvellement d'air par heure dans des appartements occupés. Dans plusieurs

bâtiments, le taux de ventilation mécanique estimé était sensiblement inférieur au taux requis de 0,30 renouvellement d'air par heure en vertu de la norme CSA F-326.

- Tous les corridors des bâtiments, sauf pour un immeuble d'Ottawa, sont dotés d'un dispositif mécanique d'air de compensation. La capacité en service de ces dispositifs, qui variait entre 20 et 80 L/s.m² par appartement, répondait aux exigences de ventilation de l'ASHRAE énoncées dans la norme 62-1989 de cet organisme ou les excédait. Les débits d'air mesurés pour le dispositif d'air de compensation des corridors variaient entre 55 % et 99 % de la capacité nominale en service de l'installation de ventilation du bâtiment.
- L'air de ventilation du corridor qui pénètre dans les appartements par la porte était négligeable dans cinq des huit bâtiments à l'étude en raison du coupe-froid placé autour de la porte d'entrée de l'appartement. Dans les trois autres bâtiments, l'air de ventilation s'infiltrant dans les appartements à partir du corridor variait de 13 à 27 L/s. L'apport d'air de ventilation dans les appartements est moindre que ce que recommande la norme CSA F-326, dont la fourchette varie de 20 à 35 L/s par appartement.
- Tous les appartements étaient pourvus de ventilateurs de salle de bains et de hottes de cuisinière. Dans tous les bâtiments, la capacité nominale de ces ventilateurs d'extraction satisfont aux exigences établies par la CSA F-326. Toutefois, les débits d'air mesurés des ventilateurs d'extraction de la salle de bains et de la cuisine ont fait ressortir que la plupart des ventilateurs de salle de bains évacuent l'air dans une proportion de 30 à 85 % de leur capacité nominale. La performance des hottes de cuisinière était légèrement supérieure à celle des ventilateurs de salle de bains, mais n'était pas acceptable pour autant. Les hottes de cuisinière évacuaient l'air dans une proportion de 50 à 90 % de leur capacité nominale.
- Les sondages menés auprès des occupants ont montré qu'environ 82 % des occupants utilisent régulièrement leur hotte de cuisinière tandis que 41 % des occupants utilisent régulièrement le ventilateur de la salle de bains.
- Ces observations ont confirmé que les bâtiments résidentiels de moyenne hauteur possèdent les dispositifs de ventilation et d'extraction requis pour respecter les exigences du Code. Cela dit, l'évaluation de la performance a mis en lumière que ces dispositifs ne fonctionnent pas au niveau de performance requis et qu'ils produisent un très faible mouvement d'air dans l'immeuble. Les dispositifs d'air de compensation fournissent de l'air frais aux corridors, mais cet air finit par retourner à l'extérieur faute d'un mécanisme de transfert approprié entre le corridor et les appartements. Ce rendement insuffisant des installations de ventilation semble aussi occasionner de hauts taux d'humidité relative, des concentrations élevées de dioxyde de carbone, de la condensation sur les fenêtres ainsi qu'une prolifération de moisissures dans plusieurs bâtiments.

Milieu intérieur

- Les sondages menés auprès des occupants ont permis d'apprendre qu'environ 16 % des occupants de certains immeubles estiment qu'ils souffrent de problèmes de santé à cause de la mauvaise qualité de l'air intérieur. Quelque 39 % des occupants se plaignent de problèmes de condensation aux fenêtres, 14 % éprouvent des problèmes de moisissures et seulement 57 % des occupants croient que la qualité de l'air de leur immeuble est acceptable.
- Dans plusieurs bâtiments, l'humidité relative et les concentrations de dioxyde de carbone dépassent les limites normales acceptables établies par Santé Canada. Les appartements de ces bâtiments présentent aussi une ventilation et un mouvement d'air insuffisants. Les plaintes des occupants sont également fréquentes. Ceux-ci semblent se plaindre le plus souvent de la mauvaise qualité ou de l'absence de ventilation et de distribution d'air.
- Les quantités de formaldéhyde et de composés organiques volatils émises par les matériaux de construction sont très inférieures aux limites acceptables dans tous les bâtiments.

- L'enquête sur le terrain a aussi permis de constater que les champs électromagnétiques sont très inférieurs à 8 milligauss dans tous les appartements analysés. Ontario Hydro recommande des niveaux maximums de 20 milligauss près de l'équipement et d'environ 8 milligauss à 0,3 m de la source.
- Les niveaux d'éclairage dans les aires communes des immeubles d'appartements de moyenne hauteur sont généralement conformes aux règles de l'art et aux exigences du Code ou les excèdent.

Utilisation de l'énergie dans les bâtiments

- L'énergie achetée dans les immeubles de moyenne hauteur varie entre 146 et 263 kWh/m² de surface de plancher par année. Le coût annuel de l'énergie varie entre 6,76 $/m² et 20,05 $/m², la moyenne oscillant autour de 10 $/m². La facture d'énergie pour chaque appartement varie de 461 $ à 1 683 $ par année. La facture d'énergie moyenne par appartement s'est établie à environ 746 $ par année si l'on en croit les données de coût disponibles pour l'année 1994.
- L'analyse des gains thermiques durant la saison de chauffage a montré que les gains solaires comblaient environ 10 % des besoins de chauffage des locaux (11,5 ± 3,1 kWh/m²) tandis que les gains internes représentaient 19 % (21,4 ± 4,7 kWh/m²) du chauffage requis pour les locaux. En moyenne, l'énergie achetée pour les besoins de chauffage des locaux est de 112,8 ± 23,6 kWh/m².
- Les déperditions thermiques durant la saison de chauffage sont réparties comme suit (pourcentage de la déperdition totale) : murs (16 %); toiture (7 %); déperditions sous la surface du sol (8 %); portes et fenêtres (30 %); fuites d'air (23 %); ventilation mécanique (16 %).
- L'analyse du bilan énergétique a montré que pour les huit immeubles à l'étude, la consommation d'énergie se répartit ainsi :

  - l'énergie achetée varie de 146 à 263 kWh/m², pour une moyenne de 184,6 ± 40,7 kWh/m²
  - le chauffage des locaux représente 43,5 % ± 8,8 %;
  - le chauffage de l'eau correspond à 25,3 % ± 2,6 %;
  - l'éclairage représente 14,8 % ± 4,8 %,
  - les besoins divers en énergie (appareils ménagers, climatisation et autres équipements) correspondent à 15,8 % ± 5,1 %.

- La comparaison montre que la valeur moyenne de la consommation énergétique pour une tour d'habitation et un immeuble résidentiel de moyenne hauteur est pratiquement la même. Comparativement à une maison individuelle, les appartements des immeubles de moyenne hauteur consomment environ 10 % moins d'énergie par unité de surface en dépit du fait que ces appartements présentent beaucoup moins de surfaces exposées que les maisons individuelles.

Dans l'ensemble, l'enquête sur le terrain et les analyses énergétiques ont fourni un grand nombre de nouvelles données sur les immeubles résidentiels de moyenne hauteur. Ces données devraient contribuer à la conception, à la construction et à la mise en service des immeubles d'appartements. De plus amples travaux seront nécessaires pour élaborer les critères de conception, les détails de construction, les installations de ventilation efficaces, les méthodes de contrôle de la qualité et de mise en service et, surtout, des directives complètes pour bien intégrer le confort des occupants avec l'efficacité énergétique dans les immeubles résidentiels de moyenne hauteur.

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FIELD INVESTIGATIONS OF INDOOR ENVIRONMENT AND ENERGY USAGE IN MID-RISE RESIDENTIAL BUILDINGS

FINAL REPORT — AUGUST 1997

1. INTRODUCTION

During the last 20 years, the percentage of multi-unit residential building stock in Canada has been increasing at a faster rate than other forms of housing. The compact design and high densities offered by multi-unit residential buildings allow for better utilization of transportation and utility infrastructure in urban settings. In 1994, there were 3.19 million dwelling units provided by multi-unit residential buildings (31% of the total) in Canada. From this 3.19 million, 936,000 dwelling are in high-rise apartments (7 storey or higher). The multi-unit residential building (MURB) sector consumed about 335 PJ of energy (24% of the residential use) in 1994[1].

The multi-unit residential stock includes a variety of building types. The MURB is generally defined as a building with more than 600 m^2 of floor area, and 3 storeys or more. The stock includes (1) mid-rise buildings of three to four storey apartment buildings which may not have elevators; (2) mid-rise buildings of five to seven storeys; (3) high-rise buildings with seven to thirty storeys; and (4) few tall apartment towers with more than 30 storeys.

Over last several years CMHC and other public and private sector agencies have undertaken pioneering studies to gain information on the existing status of the multi-unit residential building stock. These studies are generally focused on evaluating the performance of the building shell, energy use patterns, indoor air-quality, and more interestingly, the existing building conditions. Some of the relevant findings are:

- the majority of the multi-family housing stock, both public and private, was built between 1960 to 1980;
- the energy consumption of multi-unit buildings is significantly high alluding to poor thermal performance of shell, mechanical and electrical equipment and, above all, dismal performance of ventilation systems;
- the indoor air-quality in multi-unit housing is a concern in more than half of the building stock; and
- there is a significant potential for improving the general performance of multi-unit housing stock with regard to energy efficiency, building performance and comfort for occupants.

The focus of the present study is to evaluate the thermal and indoor environment performance of mid-rise buildings, more specifically three to five storey apartments. For these mid-rise buildings, the design and construction guidelines are not always clear — requirements fall somewhere in between the prescriptive requirements for low-rise buildings as defined in Part IX of the National Building Code of Canada and the general, good design practice, guidelines for high-rise buildings found in Part III and IV of National Building Code.

[1] Energy Efficiency Trends in Canada Energy Efficiency Indicators, Demand Policy and Analysis Division, NRCan, 1996

Apartment buildings are notorious for the spread of odours from one suite to another. This is indicative of the quality of the air and the performance of ventilation system in the building. Occupant surveys as well as detailed data collection were combined to characterize the air quality in mid-rise buildings, the results of which can be used in future design decisions.

The purpose of this research project was to collect indoor air quality and energy consumption data on new mid-rise residential buildings in order to help characterize this housing category. The research plan included the development of test and evaluation protocols for indoor environment parameters, energy consumption patterns and ventilation system performance parameters for mid-rise buildings. As part of the field work, a total of eight buildings were chosen for detailed evaluation; four buildings in Vancouver, two in Ottawa and two in Toronto. All the buildings were built in the last five years (1990 or later) to reflect current design and construction practices.

The detailed analysis of energy gain and loss mechanisms in mid-rise apartment buildings presented in this report should be useful to utilities, government agencies, building owners and managers, building consultants and private sector associations, such as Associations of Condominium Managers and Canadian Condominium Managers Association, in developing and implementing energy retrofit strategies. The indoor environment surveys emphasize the need for maintaining human comfort both for the purpose of occupant comfort and for sustaining the rental occupancy.

1.1. OBJECTIVES

The main objective of the study was to evaluate the indoor environment and energy consumption patterns of a selection of typical mid-rise residential buildings.

1.2. APPROACH

The following work tasks were undertaken to meet the project goals:

1) Selection of appropriate sample of 8 mid-rise apartment buildings of which 2 located in Ottawa, 2 located in Toronto and 4 located in Vancouver.
2) Development of a detailed indoor environment survey and energy audit test protocols.
3) Survey of building occupants and maintenance staff for the identification of energy and air quality related issues. A tenant questionnaire was distributed and used to determine which suites were suitable for detailed IAQ testing.
4) The following IAQ measurements were recorded in selected suites:
   - Temperature, relative humidity, CO and CO_2 data logging for a one week period
   - Formaldehyde sampling for a one week period (average concentration)
   - Volatile Organic Compounds sampling for a one week period (TVOC in two suites, GC/MS speciated in a mid-height suite)
   - Air velocity and temperature distributions
   - Ventilation rate (volumetric flow rate of corridor make-up air, corridor air entering the suite through a door, and air flow rates of bathroom and kitchen exhaust fans)
   - Electro Magnetic Field (EMF) strength (instantaneous readings)
   - Average common area lighting levels (instantaneous readings)
   - Visual inspection for fungi, mould and mildew
5) A blower door test was used to assess the airtightness of the building envelope.

6) Information was gathered on building physical and thermal characteristics, occupancy, internal loads and operational schedules for the purpose of creating an energy simulation model of the building. As part of the field survey, verified that the information provided on the building drawings was accurate. Obtained utility billing data and weather data (to match the year(s) of billing data) for the purpose of calibrating the building simulation model.

7) Data analysis was performed for indoor environment parameters. Evaluated the energy use in the building using the DOE-2.1E hourly energy simulations program.

This report presents the findings of the field surveys and energy analysis and provides discussion with regard to the functioning of a sample of eight mid-rise residential buildings.

1.3. REPORT ORGANIZATION

The report provides a brief overview of the calculation method in Section 2. Section 3 provides the results of the indoor environment surveys and Section 4 briefly provides results of energy analyses. Section 5 provides discussion on general trends and common observations. Section 6 provides conclusions and recommendations.

Appendix A-1 to A-8 provide building reports for each test building. Appendix B documents the field test protocols and field survey forms.

2. METHOD

The project involved indoor air quality and energy performance assessments of eight mid-rise multi-residential buildings. The following sections contain an outline of the methods used in evaluating the indoor air quality and energy consumption patterns of eight buildings.

2.1. CONSIDERATIONS

The following aspects were considered for reliably obtaining field data and accurately establishing the IAQ and energy performance of mid-rise multi unit residential buildings:

- *Test protocols.* Development of a detailed indoor air quality audit protocol for conducting uniform IAQ assessments in all buildings. Data gathering forms were prepared for the energy analysis using the DOE-2.1E energy simulation program.
- *Site inspection of buildings:* Each building was visited twice during the audit process.

  The first visit was an initial walk-through audit which provided general information about the building. The initial walk-through was used to become familiar with the overall building, its current use, occupant density, physical form, physical condition, mechanical and electrical systems, and accessibility. This stage of the audit was also used to collect drawings, operational logs, utility bills, and conduct surveys of building maintenance personnel.

  The detailed data collection stage included a systematic inspection and testing of the building physical, thermal, mechanical and electrical systems that affect energy consumption and quality of the indoor environment.
- *Information gathering:* The following information was gathered during the field audit:
  - physical description of the building (dimensions, orientation, etc.);
  - thermal characteristics of building components (insulation levels, solar-optical properties of windows);
  - building operation schedules for various systems (lighting, make-up air, DHW, elevators, appliances, occupancy);
  - building up-keep history for last five years and current conditions;
  - indoor air quality assessments (occupant survey and recording of IAQ parameters);
  - utility bills for at least one year, water consumption profile, and other information; and
  - the weather data for the location.
- *Energy analysis:* A detailed energy analysis was conducted using DOE-2.1E which is an hourly energy simulation model. The energy analysis involved the following aspects:
  1. Determining the base loads: Base loads are generally constant over the year. Base loads include lighting, domestic hot water, suite appliances, laundry appliances, fans and pumps, swimming pool equipment, elevators and other energy consuming equipment in the building.
  2. Performing the heat balance for the building: The heat balance analysis assists in determining the need for purchased energy for space heating to maintain the comfort conditions. The heat balance analysis takes into account the heat gains and heat losses through the building.
  3. Verifying the energy analysis with the actual utility bills: It is important to compare the energy consumption profile with actual utility data for the study period. If the

difference between the model and the actual data is more than 5%, the input data to the energy gain and loss model need to be re-examined and modified.

4. Developing the energy balance for the building: Using the base loads and the heat balance analysis an energy balance sheet is developed to determine various points of energy use in the building.

2.2. TEST PROCEDURES

The information regarding indoor air quality and energy consumption in these apartment buildings was essentially collected in three different steps.

The first step involved the distribution of an occupant survey. The second step involved the physical testing of the indoor environment, both instantaneous readings and the monitoring of the buildings for a period of one week. The third step involved an energy analysis of each building using simulation software, and the comparison of these results with billing data.

Each of these steps is discussed in more detail below.

2.2.1. Indoor Environment

The data collection form developed for this project is presented in Appendix B. Appendix B also contains a completed data collection form for each of the eight buildings, along with supporting documentation where appropriate.

Instantaneous measurements of temperature, relative humidity and carbon dioxide were made during the site visits. These measurements assisted in verifying the data loggers. The measured indoor environment parameters were compared with the requirements of ASHRAE Standard 55-81[2].

- **Occupant Survey:** A questionnaire was distributed to each tenant in each of the eight apartment buildings under investigation. Questions were designed to determine the opinions of the tenants with regard to the performance of the building. Questions pertained to:
  - the performance of the building in terms of indoor air quality, odour control and moisture control;
  - the use of the building including the presence of pets and smokers, and time spent at home; and
  - general health including identification of asthma and allergies.

  The questionnaire, both in English and French, is provided in Appendix B.
- **Carbon Monoxide:** Carbon monoxide (CO) was monitored for the period of one week using instruments such as the 'Toxilog Personal Atmospheric Monitor' by biosystems inc., the 'PhD^2 Multi Gas Detector' by biosystems inc., or the 'STX70 Personal Gas Monitoring Instrument' by Industrial Scientific Corporation. These instruments are capable of storing data. They were placed in or near the living room of the apartments. In each case a location was chosen so as not to interfere with tenant activity while monitoring representative air.
- **Temperature:** Air temperature was monitored in the suites using a YES-203 datalogger[3]. The dataloggers were placed in or near the living room, and left in place for the period of one week. Along with relative humidity and carbon dioxide, temperature was registered at

[2] ASHRAE Standard 55-81, "Thermal Environmental Conditions for Human Occupancy," ASHRAE, Inc , Atlanta, GA.

[3] YES-203 Data Recorder, by Young Environmental Systems Inc The datalogger records temperature, relative humidity and carbon dioxide

intervals of between 10 and 15 minutes. In each case, a location for the monitor was chosen so as not to interfere with tenant activity while monitoring representative air. Carbon dioxide levels measured in master bedroom.

- **Relative Humidity:** Relative humidity (RH) was monitored in the suites using a YES-203 datalogger[3]. The dataloggers were placed in or near the living room, and left in place for the period of one week. Along with temperature and carbon dioxide, RH was registered at intervals of between 10 and 15 minutes. In each case, a location for the monitor was chosen so as not to interfere with tenant activity while monitoring representative air.

- **Carbon Dioxide:** Carbon Dioxide (CO_2) was monitored in the suites using a YES-203 datalogger[3]. The dataloggers were placed in or near the living room, and left in place for the period of one week. Along with temperature and relative humidity, CO_2 was monitored at intervals of between 10 and 15 minutes. In each case, a location for the monitor was chosen so as not to interfere with tenant activity while monitoring representative air.

- **Volatile Organic Compounds (VOCs):** In this study, the concentration of total volatile organic compounds (TVOC) was determined in each of the apartments using "badges" that essentially absorb VOCs for subsequent analysis.

  Scanada Consultants purchased monitoring badges from Ortech Corporation. The badges were placed in the apartments for a period of one week and then returned to Ortech for analysis. The amount of contaminant absorbed by the badge is determined and the concentration of TVOC calculated using the amount of time the badge was exposed (the times at which devices are uncapped and recapped are recorded). TVOC results are expressed in units of milligrams of TVOCs per cubic metre (mg/m^3).

  The badges were placed with one of the other monitors in the apartments (formaldehyde, temperature, relative humidity, carbon dioxide or carbon monoxide) for the period of testing.

- **Formaldehyde:** Dosimeters are used to measure the levels of formaldehyde gas. The test-tube-like devices are uncapped and hung in or near the living room. At the end of the test period, for this project, one week, the caps are replaced. The times at which the tubes are uncapped and recapped are recorded for use in the analysis of formaldehyde gas concentrations. The tubes are sent to the lab for analysis. Results are reported in parts per million (ppm).

2.2.2. Ventilation

Ventilation was tested in several ways: whole building air leakage tests to determine the airtightness of the building shell and air leakage rates, the measurement of passive tracer sources for the period of one week to determine the effectiveness of air movement, and the instantaneous measurement of air flow from the corridor make-up air units, the exhaust fans in bathrooms and kitchens, and the flow around apartment doors.

- **Air Leakage Tests:** Airtightness was evaluated in each of the buildings using blower door tests, based on the procedure as described in CMHC's report, "Establishing the Protocols for Measuring Air Leakage and Air Flow Patterns in High-Rise Apartment Buildings"[4] and the CGSB Standard "Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method"[5].

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4 "Establishing the protocols for measuring air leakage and air flow patterns in high-rise apartment buildings", prepared by R J Magee and C.Y Shaw of National Research Council of Canada for Canada Mortgage and Housing Corporation, Ottawa, Ontario, 1990.

5 CGSB 149.10 Standard — Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method, Canadian General Standards Board, Ottawa, Ontario

The number of fans used for depressurization of the whole building varied with size of building. One person per floor was used in each building to "stand watch" while the suite doors were open, and one person operated each fan. Small wood blocks were used to keep each suite door ajar (about 4 inches) and wood/cardboard shims to keep the hallway doors fully open. Retrotec, Minneapolis and Infiltech blower doors were used. Coordination between fan operators was accomplished using phones and walkie talkies.

Pressure readings were taken in 2 to 5 Pa decrements from the maximum pressure that could be achieved (no greater than 60 Pa). Between 7 and 10 readings were obtained for each building. The spreadsheets or data sheets used in the calculation of building air leakage are provided in Appendix B.

- **Passive Sampling Devices for Air Movement Tests:** The Toronto and Vancouver buildings were tested using the system from Brookhaven National Laboratories. The Brookhaven National Laboratory Air Infiltration Measurement System (BNL/AIMS) employs a passive perfluorocarbon tracer (PFT) source and a capillary adsorption tube sampler (CATS)[6]. A time averaged concentration of the tracer is determined, and together with the source rate and the volume of the zone, an average air change rate is calculated. The lowest suite in each building was selected in order to limit the influence of air infiltration from other apartments.

  The tracer source used in these tests was meta-P-dimethylcyclohexane (m-PDCH). In each apartment, the source and the sampler were placed according to instructions provided by BNL. Some degree of error might have occurred since each apartment was considered to be one zone. More accuracy might have been achieved had the bedroom area in each unit been provided with a different tracer source. It is possible that the air change is actually slightly higher than that recorded. It was felt, however, at the initiation of the project, and in consultation with BNL, that one source and one sampler would provide a good indication of the average air change rate in each apartment.

  A similar system to the BNL/AIMS was used in Ottawa buildings (Ottawa 'B' and Ottawa 'R'). The main differences between this procedure and that described previously is that 2 emitters were deployed in each apartment, and three apartments in the building were tested. The emitters were typically placed in the living room and the bedroom, with the sampler in the living room.

- **Corridor Make-Up Air:** The corridor make-up air velocity was measured at the supply grilles on each floor using an instrument such as the TA5 Anemometer by Airflow Developments Limited. A grid pattern was used to measure the air flow at least 8 measurements taken. The volume of air supplied per grille was calculated based on the average air velocity and the free area of the grille opening.

  The air entering the apartment around the corridor door was measured using the same air velocity meter. At least four locations were measured at the bottom of the door and six to eight locations on the sides of the door. In some cases, where the door appeared to have no, or very little, leakage area, measurements were not taken. An average air velocity was determined and combined with the estimated leakage area around the door, resulting in an estimated air flow into the apartment.

- **Kitchen and Bathroom Exhaust Fans:** The kitchen and bathroom exhaust air velocities were measured at the exhaust grilles using an instrument such as the TA5 Anemometer by Airflow Developments Limited. A grid pattern was used to measure the air flow at between eight and sixteen locations each. Average air velocities were measured and the air flow (L/s) was calculated based on the size of the exhaust openings. The effective free area of duct

[6] Dietz R N , "Brookhaven Air Infiltration Measurement System," Brookhaven National Laboratory, Upton, NY 11973, April 1989

was determined using the method described in the 1993 ASHRAE Handbook of Fundamental[7]. Using the effective free area and the average air velocity, flow rate was determined. In two Ottawa buildings, fan flows were also determined using the CMHC's Duct Test Rig. This is a calibrated apparatus which provides the volumetric flow rate. Air flow measurements compared well with both these methods.

2.2.3. Electromagnetic Fields (EMFs)

The test protocol for EMF testing was based on a report prepared for IEEE[8]. Electromagnetic fields were measured in suites using a single axis measuring device, held at waist height, in three different orientations, x, y and z, where x and y are at right angles (device held parallel to the floor), and z is perpendicular. The equation $R=(X^2+Y^2+Z^2)^{1/2}$ is used to determine the resultant magnetic fields. Where possible, EMFs were measured with and without the suite power turned on in order to get the background levels as well as the 'actual' levels.

2.2.4. Lighting

Lighting in common areas only was measured for this study using the IES test protocol. A hand-held light meter, such as a General Electric 214 Triple Range Light Meter, was used. Lighting levels were measured to obtain average or typical levels as well as to identify areas of low lighting levels, if any.

2.3. ENERGY CONSUMPTION

The energy analysis was performed using the DOE-2.1E energy simulation program[9]. One of the first steps in energy analysis is to obtain the architectural and mechanical drawings for the building to be simulated. It is important to note that the goal is to create a model of the building in order to analyze thermal energy flows and not to describe in minute detail what the building looks like architecturally. The energy simulation programs (including DOE-2.1E) do *not* attempt to reconstruct the space geometrically from the input data description of the bounding surfaces. Rather, energy analysis program calculates the flow of energy *only through the surfaces which are described* in the input. Therefore, input files should be prepared for the building from an energy perspective rather than from an architectural perspective.

The DOE-2.1E documentation explains the energy simulation methods[10] and procedures for data inputs and evaluation of results[11]. The majority of information required to perform energy analyses of the buildings came from the as-built drawings. This information was complemented and/or confirmed with the completion of the energy audit forms (included as part of the air quality audit forms, see Appendix B) at the time of the site visit.

Information regarding all aspects of a building that affect energy consumption was collected, including information on lighting, occupancy, mechanical equipment and use, domestic hot water equipment and use, and electrical equipment and use, building envelope assembly, building size and building

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7 ASHRAE 1993. 1993 ASHRAE Handbook of Fundamentals Published by ASHRAE, Inc Atlanta, Georgia.

8 A Protocol for Spot Measurements of Residential Power Frequency Magnetic Fields, A Report of the IEEE Magnetic Field Task Force of the AC Fields Working Group of the Corona and Field Effects Subcommittee of the Transmission and Distribution Committee. 92 SM 460-6 PWRD, IEEE/PES 1992 Summer Meeting, Seattle. 1992

9 LBL 1994 DOE-2 1E Energy Simulation Program, Developed by Lawrence Berkeley Laboratory, January 1994

10 LBL 1994 DOE-2.1E Basics Developed by LBL and Hirsch & Associates. 1994

11 PRC-DOE2 Energy Simulation and Analysis Documentation, The Partnership for Resource Conservation, Boulder, Colorado 1994

scheduling. Air leakage data from the blower door tests were used in the program as well. The air leakage data obtained from blower door tests were modelled using the single-zone method to determine average normal air changes rates based on temperature difference and average wind speeds. The method was compared using the trace gas air change method for mid-rise apartments.[12]

The time periods used in the simulations varied depending upon the billing data that was available for each building, which was also dependent upon construction and occupancy schedules. Summaries have been used in those instances where individual apartments are metered. Billing data from as many apartments as possible were used to determine the estimated energy consumption for each of these buildings.

The purpose of the energy analyses is to determine what each of the components of each building consumes in terms of energy. Conclusions can then be drawn regarding potential for improvement for each of these components. The results of the analyses are compared with actual billing data for the buildings to ensure that the model is working correctly.

Appendix A provides a detailed evaluation of eight test buildings. Each building report is organized as per the following outline:

1) Description of Field Survey
2) Air Leakage and Ventilation Systems
   - Air Leakage Test
   - Air Change Rate Test
   - Corridor Make-up Air System
   - Kitchen and Bathroom Exhaust Fans
3) Indoor Environment Parameters
   - Occupant Survey
   - Indoor Air Temperature
   - Relative Humidity
   - Carbon Dioxide
   - Carbon Monoxide
   - Electro-Magnetic Fields (EMFs)
   - Volatile Organic Compounds (VOCs)
   - Formaldehyde
   - Lighting Levels
4) Energy Performance of the Building
   - Utility Bills
   - Energy Analysis Results
5) Discussion and Comments

[12] Ontario Hydro 1993. Air Leakage Control Assessment Procedure - Users Manual, Appendix A· Calculation Procedures for Mid-Rise Apartment Buildings, Prepared by Scanada Consultants Limited, Ottawa.

3. SURVEYS OF INDOOR ENVIRONMENT

This section briefly summarizes the indoor air quality indicators detected in the test buildings. The detailed evaluation of indoor air quality measurements for each test building is given in Appendix A. Based on field evaluation, the following discussion is provided to decipher general trends and common observations.

3.1. DESCRIPTION OF TEST BUILDINGS

The project team selected eight mid-rise residential buildings which ranged from 17 to 45 units. Two buildings are located in Ottawa, two in Toronto and four test buildings are located in Vancouver. Table 3-1 shows the detailed characteristics of the test buildings. The following are salient features:

- These test buildings were built during 1990 to 1994.
- The floor levels ranged from 3 to 4 storeys with or without basement level(s).
- The number of units ranged from 17 to 45 units.
- The majority of units were single bedroom units specifically designed for seniors.
- The wood frame construction is a popular choice for mid-rise apartments especially for three to four storey buildings. Six of the buildings had wood-frame construction.
- The glazing area ranged from 18% to 33% of the building wall area.
- Except two buildings, all others had underground parking garages either covering the full or partial area of the building foot print.
- Electric baseboards provide space heating in four buildings while natural gas central hydronic radiators provide the space heating in the other four buildings.
- Seven buildings had corridor make-up air systems. In most of the buildings, the make-up air fans operate continuously.
- The corridor make-up air heating is accomplished using the natural gas in seven buildings while the remainder building did not have any corridor make-up air system.
- The domestic hot water heating is supplied by natural gas central hydronic system in six buildings while the other two buildings have individual electric hot water tanks in units.
- Each unit has a kitchen exhaust fan and a bathroom exhaust fan which can be used by the occupant when needed.
- There was no dedicated suite ventilation systems found in any of these test buildings.
- Three buildings use energy efficient lighting fixtures (T8, compact fluorescent lamps, low-wattage exit signs) in common areas and exterior lighting while the other five buildings have conventional lighting fixtures. The survey showed that conventional lighting fixtures are used by occupants.
- All buildings have common laundry and washing facilities.

Table 3-1: Characteristics of Test Buildings.

			Ottawa 'B'	Ottawa 'R'	Toronto 'L'
1	**Location**		Ottawa	Ottawa	Toronto
2	**Year of Construction**		1990	1991	1991
3	**Number of Floors**		3.5	4	4
4	**Type of Construction**		Wood frame construction. Factory-built modules assembled at the site.	Brick veneer steel studs	Brick veneer steel studs
5	**Type of occupancy**		Family	Seniors/Family	Seniors/Family
6	**Suites**	Bachelor suites		1	
		1-bedroom	12	12	12
		2-bed-room	11	14	17
		3 or more bedroom suites		8	22
		Total	23	35	51
		Underground parking garage	No	Yes	Yes
7	**Dimensions**	Floor area, m2	1,629	2,937	4,301
		Volume, m3	3,788	6,408	10,365
		Exposed building envelope area, m2	1,409	1,919	3,002
		Window area, m2	183	269	879
		Exterior door area, m2	155	88	128
		Percentage of glazing/wall area	24.0%	18.6%	33.5%
8	**Space Heating System**	Main space heating fuel	Electric	Electric	Natural gas
		Type of system	Electric baseboards	Electric baseboards	Central hydronic system
		Operation schedule	Individually thermostat controlled	Individually thermostat controlled	Indoor/outdoor temperature controller and in suite thermostats
9	**Make-up air heating system (Corridor air)**	Type of fuel	None	Natural gas	Natural gas
		Type of system	None	Forced-air corridor system	Forced-air corridor system
		Operation schedule	None	supply air temperature thermostat	supply air temperature thermostat
10	**DHW System**	Type of fuel	Electric	Electric	Natural gas
		Type of system	Individual electric water tank	Individual electric water tank	Central hydronic DHW
		Operation schedule	Thermostat set at 60 °C.	Thermostat set at 60 °C.	Thermostat set at 65 °C.
11	**Ventilation System**	Make-up air system (Corridor air)	None	Forced-air corridors	2 Forced-air; 1,982 L/s and 1,382 L/s
		Suite ventilation	None	None	None
		Kitchen hood fans	Individual fans each rated at 40 L/s	Individual fans each rated at 80 L/s	Individual fans each rated at 40 L/s
		Bathroom exhaust fans	Individual fans each rated at 25 L/s	Individual fans each rated at 25 L/s	Individual fans each rated at 25 L/s
		Garage/service room exhausts	None	Parking garage exhaust fans CO controlled	Parking garage exhaust fans timer controlled - runs @ 12 hrs a day
		Other	Basement corridor has a manually operated exhaust fan (80 L/s).		
12	**Envelope characteristics (Effective values determined using DOE-2.1E calculations)**	Measured airtightness	2.31 L/s.m2 at ΔP of 75 Pa	2.23 L/s.m2 at ΔP of 75 Pa	3.43 L/s.m2 at ΔP of 75 Pa
		Walls	RSI 2.64	RSI 2.14	RSI 2.68
		Roof	RSI 4.54	RSI 3.37	RSI 3.46
		Windows	RSI 0.32	RSI 0.28	RSI 0.22
		Exterior Doors	RSI 0.36	RSI 0.40	RSI 0.48
13	**Lighting System**	Type of common area lights	Compact fluorescent and ee lamps	Conventional lamps	Conventional lamps
		Typical suite lamps	Conventional lamps	Conventional lamps	Conventional lamps
14	**Elevators**	Number	None	2	2
		Type of equipment		Conventional electric	Conventional electric
15	**Appliances**	Common area	Laundry and washing	Laundry and washing	Laundry and washing
		Suites	kitchen + entertainment appliances	kitchen + entertainment appliances	kitchen + entertainment appliances
16	**Other comments**		Observed severe window condensation	Found some window condensation	

Table 3-1: Characteristics of Test Buildings.

			Toronto 'S'	Vancouver 'LV'	Vancouver 'MV'
1	Location		Toronto	Vancouver	Vancouver
2	Year of Construction		1994	1992	1993
3	Number of Floors		3	4	3
4	Type of Construction		Wood frame construction.	Wood frame construction.	Wood frame construction.
5	Type of occupancy		Seniors	Seniors	Seniors
6	Suites	Bachelor suites	11		
		1-bedroom	6	45	45
		2-bed-room			
		3 or more bedroom suites			
		Total	17	45	45
		Underground parking garage	Partial	Partial	Partial
7	Dimensions	Floor area, m2	871	3,060	3,268
		Volume, m3	2,001	7,466	7,966
		Exposed building envelope area, m2	890	2,599	2,690
		Window area, m2	142	468	538
		Exterior door area, m2	18	113	99
		Percentage of glazing/wall area	18.0%	22.3%	23.7%
8	Space Heating System	Main space heating fuel	Natural gas	Natural gas	Electricity
		Type of system	Central hydronic system	Central hydronic, radiant floor heating	Electric baseboards
		Operation schedule	Indoor/outdoor temperature controller and in suite thermostats	in suite thermostats	in suite thermostat
9	Make-up air heating system (Corridor air)	Type of fuel	Natural gas	Natural gas	Natural gas
		Type of system	Forced-air corridor system	Forced-air corridor system	Forced-air corridor system
		Operation schedule	supply air temperature thermostat	supply air temperature thermostat	supply air temperature thermostat
10	DHW System	Type of fuel	Natural gas	Natural gas	Natural gas
		Type of system	Central hydronic DHW	Central hydronic DHW	Central hydronic DHW
		Operation schedule	Thermostat set at 60 °C.	Thermostat set at 65 °C.	Thermostat set at 65 °C.
11	Ventilation System	Make-up air system (Corridor air)	1 Forced air fan, 2,500 CFM	Two forced air fans, each 3,800 CFM	Two forced air fans, each 750 CFM
		Suite ventilation	None	None	None
		Kitchen hood fans	Individual fans each rated at 40 L/s	Individual fans each rated at 100 L/s	Individual fans each rated at 100 L/s
		Bathroom exhaust fans	Individual fans each rated at 25 L/s	Individual fans each rated at 100 L/s	Individual fans each rated at 50 L/s
		Garage/service room exhausts	Exhaust fan, 100 CFM	Exhaust fan, 300 CFM	Exhaust fan, 400 CFM
		Other			
12	Envelope characteristics (Effective values determined using DOE-2.1E calculations)	Measured airtightness	3.35 L/s.m2 at ΔP of 75 Pa	3.03 L/s.m2 at ΔP of 75 Pa	3.60 L/s.m2 at ΔP of 75 Pa
		Walls	RSI 2.52	RSI 2.52	RSI 2.62
		Roof	RSI 3.25	RSI 3.25	RSI 3.25
		Windows	RSI 0.30	RSI 0.25	RSI 0.25
		Exterior Doors	RSI 0.60	RSI 0.40	RSI 0.40
13	Lighting System	Type of common area lights	Energy efficient fixtures	Energy efficient fixtures	Conventional fixtures
		Typical suite lamps	Conventional lamps	Conventional lamps	Conventional fixtures
14	Elevators	Number	None	2	2
		Type of equipment		Conventional	Conventional
15	Appliances	Common area	Laundry and washing	Laundry and washing	Laundry and washing
		Suites	kitchen + entertainment appliances	kitchen + entertainment appliances	kitchen + entertainment appliances
16	Other comments				

Table 3-1: Characteristics of Test Buildings.

			Vancouver 'SB'	Vancouver 'W'
1	**Location**		Vancouver	Vancouver
2	**Year of Construction**		1993	1993
3	**Number of Floors**		4	4
4	**Type of Construction**		Wood frame construction.	Wood frame construction.
5	**Type of occupancy**		Seniors	Seniors
6	**Suites**	Bachelor suites		
		1-bedroom	30	36
		2-bed-room		
		3 or more bedroom suites	1	
		Total	31	36
		Underground parking garage	None	Yes
7	**Dimensions**	Floor area, m2	2,705	2,519
		Volume, m3	6,739	6,138
		Exposed building envelope area, m2	2,409	2,139
		Window area, m2	434	342
		Exterior door area, m2	95	95
		Percentage of glazing/wall area	21.9%	20.4%
8	**Space Heating System**	Main space heating fuel	Electricity	Natural gas
		Type of system	Electric baseboards	Central hydronic
		Operation schedule	in suite thermostat	in suite thermostats
9	**Make-up air heating system (Corridor air)**	Type of fuel	Natural gas	Natural gas
		Type of system	Forced-air corridor system	Forced-air corridor system
		Operation schedule	supply air temperature thermostat	supply air temperature thermostat
10	**DHW System**	Type of fuel	Natural gas	Natural gas
		Type of system	Central hydronic DHW	Central hydronic DHW
		Operation schedule	Thermostat set at 65 °C.	Thermostat set at 65 °C.
11	**Ventilation System**	Make-up air system (Corridor air)	One forced air fan, 1,500 CFM	Two fans, 2,300 and 2,700 CFM
		Suite ventilation	None	None
		Kitchen hood fans	Individual fans each rated at 80 L/s	Individual fans each rated at 80 L/s
		Bathroom exhaust fans	Individual fans each rated at 50 L/s	Individual fans each rated at 100 L/s
		Garage/service room exhausts		Supply fan for garage lobby 300 CFM, and an exhaust fan, 300 CFM
		Other		
12	**Envelope characteristics (Effective values determined using DOE-2.1E calculations)**	Measured airtightness	3.58 L/s.m2 at ΔP of 75 Pa	3.49 L/s.m2 at ΔP of 75 Pa
		Walls	RSI 2.52	RSI 2.32
		Roof	RSI 3.25	RSI 3.25
		Windows	RSI 0.25	RSI 0.25
		Exterior Doors	RSI 0.40	RSI 0.40
13	**Lighting System**	Type of common area lights	Conventional fixtures	Conventional fixtures
		Typical suite lamps	Conventional fixtures	Conventional fixtures
14	**Elevators**	Number	2	2
		Type of equipment	Conventional	Conventional
15	**Appliances**	Common area	Laundry and washing	Laundry and washing
		Suites	kitchen + entertainment appliances	kitchen + entertainment appliances
16	**Other comments**			

3.2. AIR LEAKAGE AND VENTILATION SYSTEMS

3.2.1. Air Leakage Characteristics

The air leakage characteristics of the building envelope was determined using whole building airtightness tests. These airtightness tests were conducted using the test protocol developed by National Research Council for CMHC[13]. The airtightness test results were evaluated using the analytical procedures described in the CGSB Standard 149.10.[14] Table 3-2 and Figure 3-1 shows the air leakage characteristics of buildings. As shown, the air leakage rate ranged from 2.23 L/s.m^2 to 3.60 L/s.m^2 at 75 Pa pressure difference. It is interesting to note that the air change rate per hour at the 50 Pa pressure difference, which is commonly used in describing the airtightness for low-rise residential buildings, did not correlate in a similar fashion as that of the envelope airtightness expressed in terms of a unit envelope area. The AC/hr at 50 Pa pressure difference varied from as low as 1.78 to 4.10 for these buildings.

The measured values of airtightness for various buildings are significantly higher than what can be expected in buildings with properly designed, installed and constructed air barrier systems which should range from as low as 0.3 to 1.7 L/s.m^2 at 75 Pa pressure difference. The 1995 National Building Code suggests a range of 0.05 to 0.15 L/sm^2 at 75 Pa pressure difference. The measured results, however compared well with some of the findings for older apartment buildings. For example, according to a CMHC report[15] average airtightness values for apartment buildings are between 0.68 and 10.9 L/s.m^2 at a pressure difference of 75 Pa across the exterior wall. The wall corners, roof/wall joint, window and wall joints, balcony door frame and wall joints, and basement/ground floor connections seem to be the cause of the poor airtightness in most buildings.

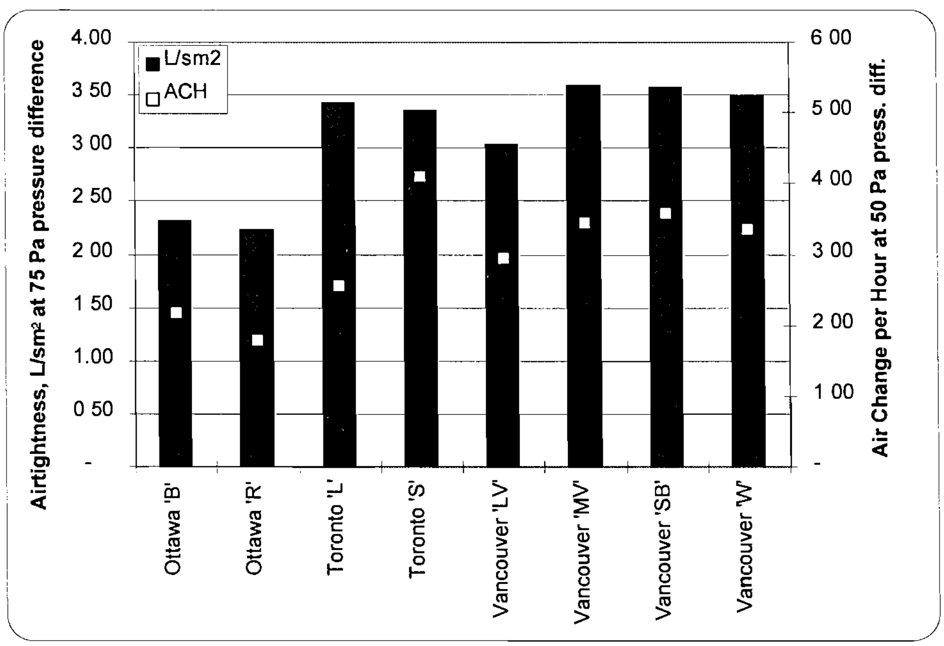


Figure 3-1: Air leakage characteristics of mid-rise buildings.

13 CMHC 1990 Establishing the protocols for measuring air leakage and air flow patterns in high-rise apartment buildings. Prepared by R J Magee and C Y Shaw of IRC/NRC for CMHC, Ottawa.

14 CGSB 1988 CGSB Standard 149 10 (new draft - 1994) — Determination of Airtightness of Building Envelopes by the Fan Depressurization Method, Canadian General Standards Board, Ottawa, Ontario

15 "Field Investigation Survey of Airtightness, Air Movement and Indoor Air Quality in High-Rise Apartment Buildings - Summary Report, CMHC, 1993

Table 3-2: Air leakage characteristics of buildings.

Building	Airtightness of Envelope		Air Change/ hour at 50 Pa
	L/sm² at 50 Pa	L/sm² at 75 Pa	
Ottawa 'B'	1.72	2.31	2.17
Ottawa 'R'	1.65	2.23	1.78
Toronto 'L'	2.45	3.43	2.55
Toronto 'S'	2.56	3.35	4.10
Vancouver 'LV'	2.34	3.03	2.94
Vancouver 'MV'	2.84	3.60	3.45
Vancouver 'SB'	2.78	3.58	3.58
Vancouver 'W'	2.67	3.49	3.35
Average	**2.38**	**3.13**	**2.99**

3.2.2. Air Change Rate Test

The air change rate was determined in three units using the passive sampling devices (PFT) for a period of one week. Table 3-3 shows the normal air change rate measured during the one week period. The air change rate includes effects of both the natural air change due to the air leakage, interzone air movement and the mechanical ventilation in the building. It should be noted that occupants of test units were requested to close windows during the sampling period; however, the results showed that some occupants did not comply with the request.

Table 3-3 presents the measured results of the PFT analysis. Estimations of the air leakage and mechanical ventilation components were determined using the ALCAP method based on measured airtightness data. As shown, in seven buildings the mechanical ventilation rate is lower than what is required by Standards CSA F-326 and ASHRAE 62. The 1990 NBC Part VI refers to CSA F-326 for the ventilation requirements in suites. It should be noted that the requirements in the Standards are for the ventilation rates or air change provided by *intentional* systems such as windows. The air infiltration may vary for individual suites as shown in the table for Ottawa 'B' and Ottawa 'R' building.

Table 3-3: Air change rates based on passive sampling methods.

Building	Unit	Measured Result (AC/hr)	Estimated		Requirements (Normal Air Change Rate)	
			Air Leakage (AC/hr)	Mechanical (AC/hr)	CSA F-326, (AC/hr)	ASHRAE 62, AC/hr)
Ottawa 'B'	5	0 75	0.63	0 12	0 30	0 35
	15	1.10	0 89	0 21	0 30	0.35
	19	2 04	1 87	0 17	0 30	0 35
Ottawa 'R	106	1 06	0 39	0.67	0 30	0 35
	207	0.60	0 36	0.24	0.30	0.35
	404	0.47	0.37	0 10	0 30	0.35
Toronto 'L'	111	0 71	0.45	0 26	0 30	0.35
	209	0.62	0.42	0 20	0 30	0.35
	405	0.55	0.46	0 09	0.30	0.35
Toronto 'S'	103	1.06	0 80	0 26	0.30	0.35
	205	0.71	0 56	0 15	0 30	0.35
	306	0.86	0.59	0.27	0.30	0.35
Vancouver 'LV	111	0.09	0.35	-0.26	0.30	0.35
Vancouver 'M	112	0.47	0.35	0 12	0.30	0.35
	217	0.55	0.32	0 23	0 30	0.35
	304	0.62	0.36	0 26	0.30	0 35
Vancouver 'SB	203	0.75	0 60	0 15	0 30	0.35
Vancouver 'W'	203	1 00	0 66	0.34	0.30	0.35
	306	0.91	0 46	0 45	0 30	0.35
	403	0 72	0 41	0.31	0.30	0.35

* Ottawa 'B' Unit 19 It seems that occupants kept the window opened during the test period.

** Vancouver 'LV' Unit 111 The PFT concentration was significantly higher than the other buildings (almost ten-fold higher) which means that the ventilation rate was almost ten-fold lower It is felt that the results for this building may not be accurate due, perhaps, to contamination of the sampler by the source either prior to or after the test period.

3.2.3. Corridor Make-Up Air

The purpose of the measurements of the corridor make-up air flows were to determine the performance of make-up air ventilation systems. In measuring the flow of the corridor make-up air, grilles were left as found; that is, if they were partially closed, they were left that way. The required make-up air listed in the table below is the ventilation capacity as stated on the mechanical drawings or capacity of fans noted from the field survey.

As shown in Table 3-4 and Figure 3-2, the make-up ventilation system provided the necessary air flows to corridors. Review of building drawings showed that the design capacity was generally based on 20 to 80 L/s per suite. For one bedroom units, the design capacity is about 20 to 25 L/s and 40 to 80 L/s per suite for more than one-bedroom suites. Measured air flows showed that in some buildings, the make-up air system needs balancing. The measured results showed that systems provided 55% to 99% of the rated capacity in the buildings. It is suspected that the unaccounted air flow capacity is either lost in distribution system or the fan capacity has reduced.

Table 3-4: Measurements of corridor make-up air.

Building	Floor	Measured Air Flow (L/s)	Required by Designer (L/s)	Percentage of Capacity
Ottawa 'B'*	bsm't	n/a	none	
	2nd	n/a	none	
	3rd	n/a	none	
Ottawa 'R'	1st	440	526	84%
	2nd	223	526	42%
	3rd	640	526	122%
	4th	440	526	84%
Toronto 'L' **	1st	606	826	73%
	2nd	677	826	82%
	3rd	521	826	63%
	4th	716	826	87%
Toronto 'S' **	1st	255	393	65%
	2nd	280	393	71%
	3rd	295	393	75%
Vancouver 'LV' **	1st	450	897	50%
	2nd	479	897	53%
	3rd	602	897	67%
	4th	634	897	71%
Vancouver 'MV' **	1st	381	315	121%
	2nd	291	315	92%
	3rd	180	315	57%
Vancouver 'SB' **	1st	35	177	20%
	2nd	174	177	98%
	3rd	70	177	40%
	4th	111	177	63%
Vancouver 'W' ***	1st	618	400	155%
	2nd	586	645	91%
	3rd	611	645	95%
	4th	508	645	79%
	garage lobby	118	142	83%

* Corridor male-up not required by designer as well as not installed.

** The drawings indicate capacity of the ventilation equipment, which has been divided equally between the floors

*** The drawings indicate design air flow per floor

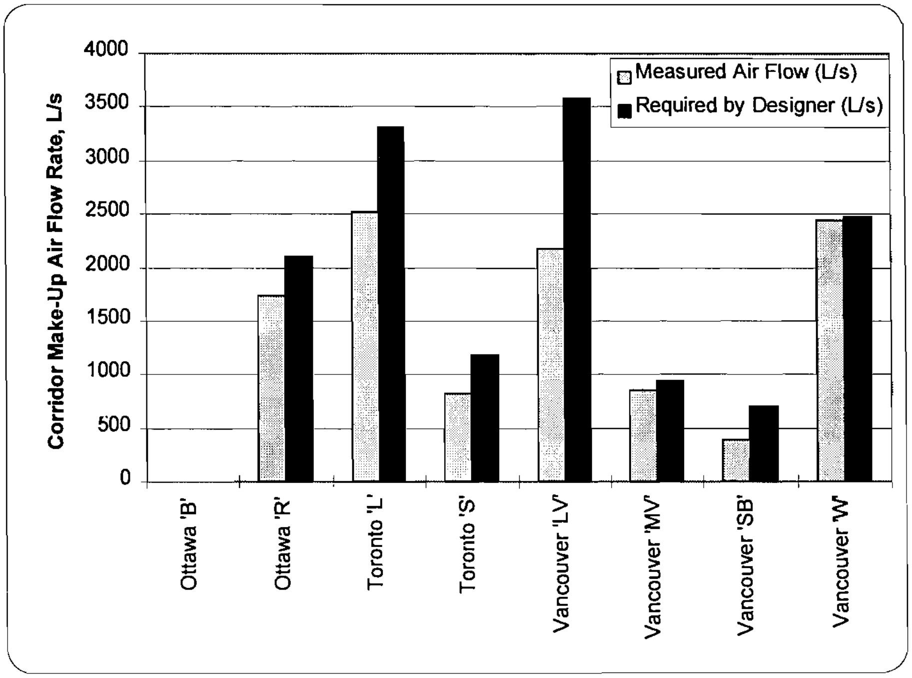


Figure 3-2: Performance of corridor make-up air system in mid-rise buildings.

Table 3-5: Air supply to suites from the apartment doorway.

Building	Unit	Flow (L/s)	Required Air Supply as per F-326 (L/s)
Ottawa 'B'	5	0	25
	15	0	25
	19	0	30
Ottawa 'R'	106	17	35
	207	18	35
	404	13	25
Toronto 'L'	111	13	30
	209	20	30
	405	17	35
Toronto 'S'	103	19	25
	205	27	25
	306	15	20
Vancouver 'LV'	111	1	25
	301	1	25
	404	0	25
Vancouver 'MV'	112	7	25
	217	9	25
	304	6	25
Vancouver 'SB'	203	5	25
	304	5	25
	403	0	25
Vancouver 'W'	203	1	25
	306	13	25
	403	0	25

The measured air flow around each of the apartment corridor doors is presented in Table 3-5. The required air flow is calculated based on the requirements in Standard F326 as determined by specific room requirements[16] (e.g., living rooms require 5 L/s, master bedrooms require 10 L/s, etc.). It is difficult to measure the gap area around the apartment door; however, these areas have been calculated as carefully as possible.

It should be noted that in several buildings, the suite door leading to the corridor is weatherstripped. These units had negligible air flows through the apartment door.

3.2.4. Kitchen and Bathroom Exhaust Fans

The air flow rates were measured for kitchen and bathroom exhaust fans in the test units. Table 3-6 shows the measured air flows of kitchen and bathroom fans in test units. As per the Standard F-326, the kitchen fan should have a minimum designed capacity of 50 L/s and bathroom fan with 25 L/s. In some units the air flow rates through kitchen and bathroom fans exceeded the minimum requirements. In some cases, although the design capacity of fans was higher than what is required, the fans were significantly handicapped in meeting the minimum requirements. The reason for the under-performance of these fans was not investigated due to the scope and nature of the present study.

Table 3-6: Performance of kitchen and bathroom exhaust fans.

Building	Unit	Kitchen		Bathroom
		Flow (High) (L/s)	Flow (Low) (L/s)	Flow (L/s)
Ottawa 'B'	5	6	n/a	7
	15	8	n/a	6
	19	9.5	n/a	7.5
Ottawa 'R'	106	51	n/a	16
	207	67	n/a	12
	404	35	n/a	18
Toronto 'L'	111	24		16
	209	15		12
	405	27		20
Toronto 'S'	103	19		16
	205	35	33	21
	306			23
Vancouver 'LV'	111	75	56	79
	301	86	58	79
	404	91	67	108
Vancouver 'MV'	112	141	73	41
	217	n/a	n/a	62
	304	101	72	52
Vancouver 'SB'	203	86	53	88
	304	86	68	76
	403	89	65	80
Vancouver 'W'	203	62	56	78
	306	72	52	71
	403	73	61	88

[16] CAN/CSA-F326-M91 "Residential Mechanical Ventilation Requirements," Table 1, Published by Canadian Standards Association.

3.3. INDOOR ENVIRONMENT PARAMETERS

The indoor environment surveys were conducted in each building. Indoor air quality samplers were placed in three representative occupied units in the building. Appendix B provides details of field test protocols and the criteria used in selecting the test units in the building.

3.3.1. Occupant Survey

A questionnaire was distributed to each tenant in each of the eight apartment buildings under investigation. Questions were designed to determine the opinions of the tenants with regard to the performance of the building and status of the indoor air quality. The sample questionnaire, both in English and French, is provided in Appendix B. Questions pertained to:

1) the performance of the building in terms of indoor air quality, odour and moisture control;
2) the use of the building including the presence of pets and smokers, and time spent at home; and
3) general health including identification of asthma and allergies.

The survey questionnaire was distributed to all 284 apartments in eight buildings. Completed survey forms were returned by 170 tenants. The response rate ranged from 20% to 94% and averaged at about 60% as shown in Table 3-7.

Table 3-7: Questionnaire Response Rate

Building	Total # Units	# Responses	Response Rate (%)
Ottawa 'B'	23	11	48%
Ottawa 'R'	35	19	54%
Toronto 'L'	51	10	20%
Toronto 'S'	17	13	76%
Vancouver 'LV'	47	25	53%
Vancouver 'MV'	45	30	67%
Vancouver 'SB'	30	28	93%
Vancouver 'W'	36	34	94%
Total	**284**	**170**	**60%**

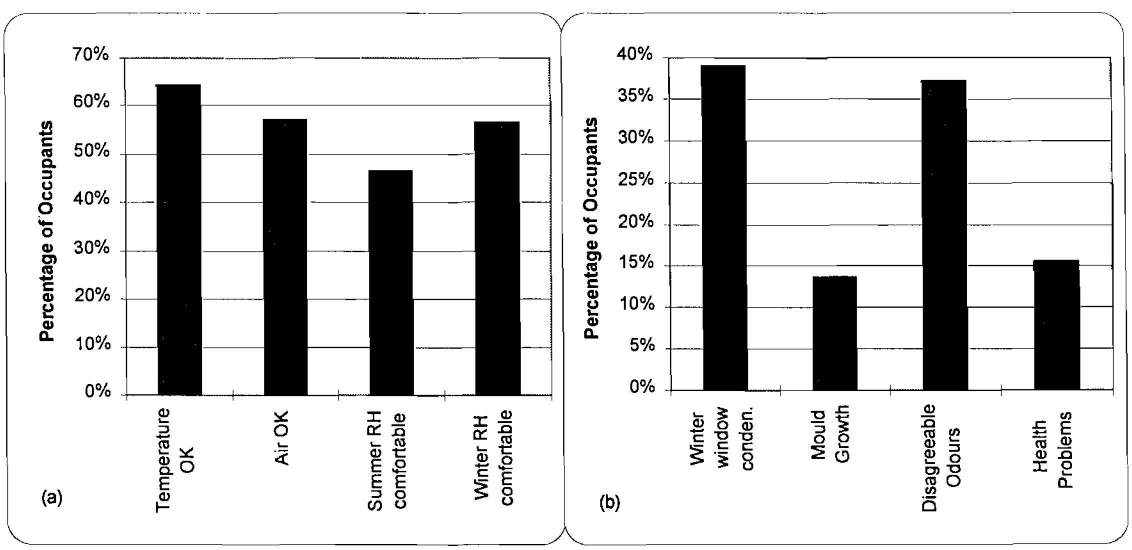


Figure 3-3: Occupant responses: (a) reply to temperature and RH parameters, and (b) reply to comfort criteria.

Table 3-8: Summary of Tenant Surveys

	Ottawa 'B'	Ottawa 'R'	Toronto 'L'	Toronto 'S'	Vancouver 'LV'	Vancouver 'MV'	Vancouver 'SB'	Vancouver 'W'
Temperature OK	**27%**	**47%**	**80%**	**54%**	**68%**	**93%**	**50%**	**59%**
too hot	9%	0%	10%	23%	4%	3%	4%	29%
too cold	0%	21%	0%	0%	4%	3%	4%	0%
inconsistent	64%	21%	10%	23%	12%	0%	43%	15%
Air OK	**27%**	**58%**	**50%**	**69%**	**44%**	**97%**	**57%**	**47%**
stale	0%	16%	10%	8%	12%	0%	21%	21%
stuffy	55%	26%	30%	15%	36%	0%	11%	29%
drafty	18%	5%	10%	0%	4%	3%	7%	6%
Summer RH comfortable	**18%**	**32%**	**20%**	**46%**	**48%**	**90%**	**61%**	**50%**
too dry	9%	5%	10%	8%	20%	10%	21%	21%
too humid	73%	53%	60%	15%	24%	0%	11%	24%
Winter RH comfortable	**27%**	**42%**	**50%**	**46%**	**72%**	**73%**	**54%**	**65%**
too dry	18%	16%	50%	46%	12%	17%	29%	29%
too humid	55%	42%	0%	0%	12%	7%	11%	3%
Tenants with								
Winter window condensation	91%	84%	80%	8%	4%	10%	21%	15%
Mould Growth	45%	26%	20%	0%	4%	7%	14%	0%
Disagreeable Odours	91%	53%	40%	31%	20%	13%	32%	44%
Health Problems attributed to building	9%	16%	30%	31%	16%	7%	4%	12%
Use of a Humidifier								
Never	**55%**	**37%**	**60%**	**85%**	**88%**	**70%**	**79%**	**85%**
Occasionally	27%	26%	30%	15%	8%	23%	18%	12%
At night	9%	0%	10%	0%	0%	0%	0%	0%
Frequently	9%	32%	0%	0%	0%	7%	4%	3%
Use of kitchen exhaust								
Never	**0%**	**5%**	**0%**	**0%**	**8%**	**7%**	**4%**	**3%**
Only when cooking	73%	95%	80%	100%	64%	83%	89%	85%
Frequently	27%	0%	20%	0%	28%	7%	7%	12%
Use of bathroom exhaust								
Never	**0%**	**5%**	**0%**	**0%**	**16%**	**10%**	**14%**	**3%**
Occasionally	27%	0%	60%	46%	36%	47%	50%	50%
Frequently	73%	5%	40%	46%	44%	37%	32%	44%
On with the lights	0%	89%	0%	8%	4%	3%	4%	3%

Please note that the total sum of percentage may not add to 100% due to non response of some questions by occupants.

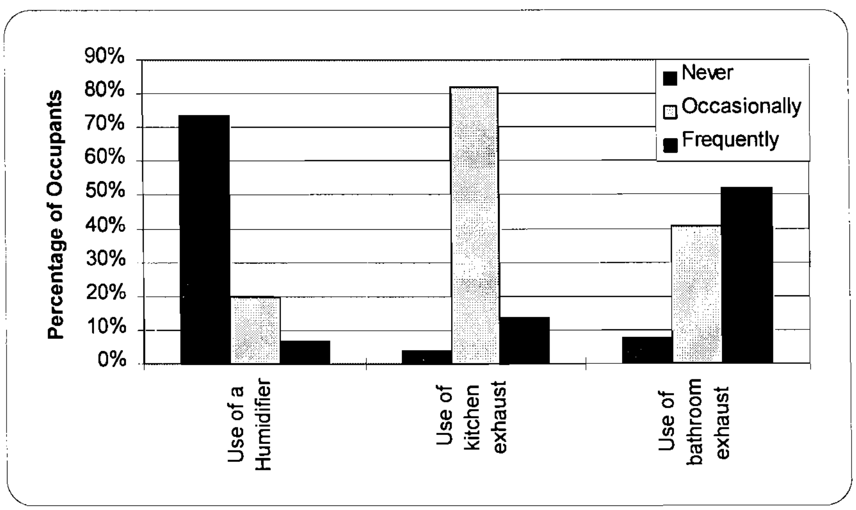


Figure 3-4: Responses of occupants with regard to the use of common exhaust and humidification issues.

Table 3-8 shows the detailed summary of responses received from tenants with regard to indoor air quality parameters in each building. Figure 3-3 and Figure 3-4 show the summary of responses with regard to indoor environment in the building. The general trends were as follows:

- *Indoor air temperature:* About 64% of occupants felt that indoor temperature was acceptable. From building to building, the occupant response for acceptable air temperature ranged from 27% to 93%.
- *Perceptions for general quality of air in the building:* About 57% of occupants felt that quality of indoor air was acceptable. From building to building, the occupant response for acceptable air quality ranged from 27% to 97%.
- *Relative humidity during summer months:* About 47% of occupants felt that RH level during summer months was acceptable. From building to building, the occupant response for acceptable levels of RH ranged from 18% to 90%.
- *Relative humidity during winter months:* About 57% of occupants felt that RH level during winter months was acceptable. From building to building, the occupant response for acceptable levels of RH ranged from 27% to 73%.
- *Problems of window condensation in the building:* About 39% of occupants complained about window condensation mostly during heating season. From building to building, the occupant complaints for window condensation ranged from 4% to 91%.
- *Problems of mold growth in the building:* About 14% of occupants reported mold growth in suites. From building to building, the occupant complaints for mold growth ranged from none to 45% It is interesting to note that mold growth complaints were higher where the winter RH levels were also significantly high.
- *Complaints of disagreeable odours in the building:* About 37% of occupants complained about disagreeable odours. From building to building, the occupant complaints for odours ranged from 13% to 91%. The response to the question did not correlate the response to a question pertaining to general quality of air in the building.
- *Attribution of building indoor environment to health problems:* About 16% of tenants reported that their poor health symptoms were due to indoor air quality in the building. From building to building, the occupant complaints regarding the health problems related to indoor air quality ranged from 4% to 31% Most tenants, however, did not respond to questions pertaining to specific health symptoms.
- *Use of humidifier:* About 74% of occupants never used humidifiers and the remaining may have used humidifier sometimes The use of humidifier was prominent in buildings providing seniors accommodation
- *Use of kitchen exhaust fans:* About 82% of occupants did use kitchen fans while cooking, and about 4% never used any kitchen exhaust fan
- *Use of bathroom exhaust fans:* About 41% of occupants did use bathroom exhaust fans while using bathrooms, and about 8% never used any bathroom exhaust fan.

The occupant survey revealed that a significant portion of tenants did not find indoor air quality acceptable to their liking The use of occupant-controlled exhaust fans was also low in many buildings. It seems that ventilation and air movements were major causes of occupant discomfort.

3.3.2. *Indoor Air Temperature*

Indoor air temperatures were measured in three test units in each apartment building. The continuous data loggers were set to record indoor air temperature at 10 minutes intervals for a period of seven to ten days. Figure 3-5 shows ranges of indoor air temperature in test suites. As shown in this graph, the indoor air temperature varied from as low as 15.5 °C in an apartment unit to 28.7 °C in another. In each suite, the variation in indoor air temperature ranged from 2.2 °C to 8 °C.

According to ASHRAE Standard 55-1992[17], the indoor air temperature should be 21 to 24.5 °C during winter months, and 22.5 to 26 °C during summer months. This requirement is based criteria that 80% of the occupants will be satisfied with such comfort conditions. Figure 3-5 shows that in most units, the indoor air temperature remained within the comfort zone.

Table 3-9 shows a list of identifiers of suite numbers for each building. This list of identifiers is used in subsequent analysis of other parameters.

Table 3-9: Identification tags for buildings and units.

Building	Unit Number	Identification Tag
Ottawa 'B'	5	OB-5
	15	OB-15
	19	OB-19
Ottawa 'R'	106	OR-106
	207	OR-207
	404	OR-404
Toronto 'L'	111	TL-111
	209	TL-209
	405	TL-405
Toronto 'S'	103	TS-103
	205	TS-205
	306	TS-306
Vancouver 'LV'	111	VLV-111
	301	VLV-301
	404	VLV-404
Vancouver 'MV'	112	VMV-112
	217	VMV-217
	304	VMV-304
Vancouver 'SB'	203	VSB-203
	304	VSB-304
	403	VSB-403
Vancouver 'W'	203	VW-203
	306	VW-306
	403	VW-403

3.3.3. *Relative Humidity*

Relative humidity measurements were taken in three test units in each apartment building. The continuous data loggers were set to record RH values every 10 min interval for a period of seven to ten days. Figure 3-6 shows ranges of relative humidity in the test suites. As shown in this graph, the relative humidity varied from as low as 8% in an apartment unit to 61% in another. In each suite, the variation in RH ranged from 10% to 40%.

According to ASHRAE Standard 55-1992[17], the indoor RH should be 20% to 40% during winter months, and 40 to 60% during summer months. Figure 3-6 shows that in buildings located in Ontario, the indoor relative humidity remained below the acceptable range. Indoor air was found to

[17] ASHRAE 1992. "Thermal Environmental Conditions for Human Occupancy," ASHRAE Standard 55-1992. Published by ASHRAE

be too dry in Ontario buildings. The RH levels in Vancouver buildings were found to be within acceptable limits.

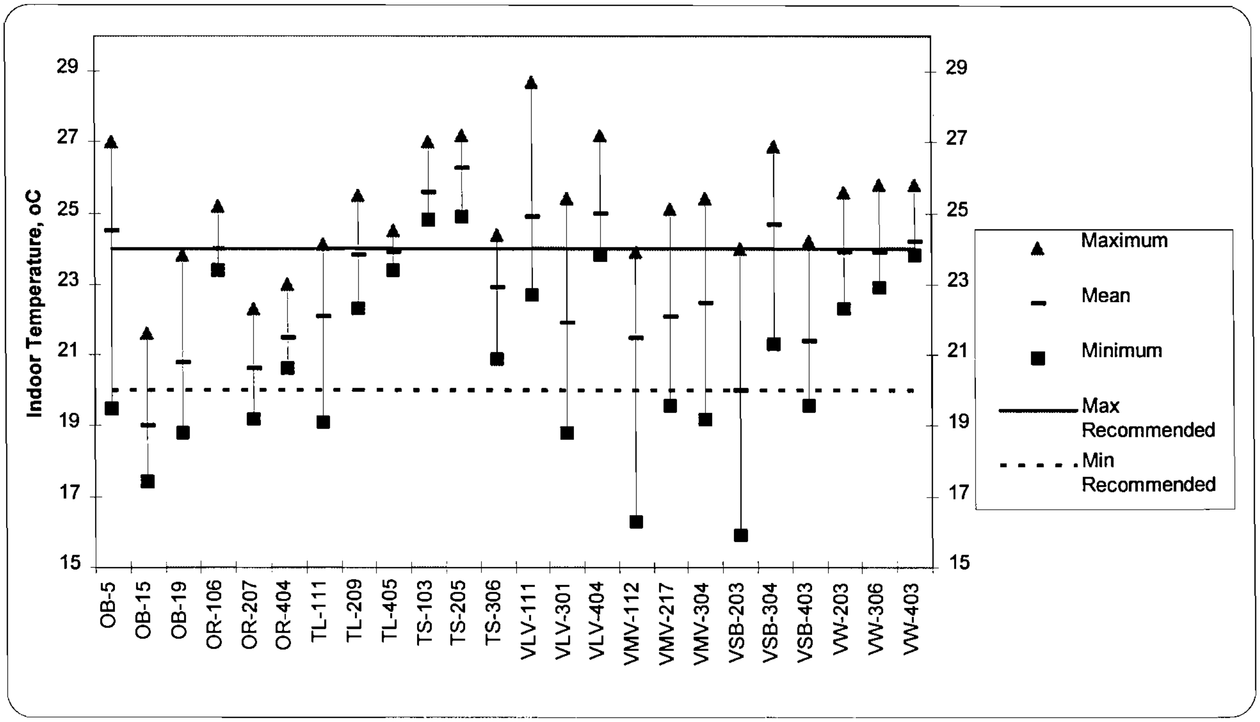


Figure 3-5: Range of variations in indoor air temperature in test apartments.

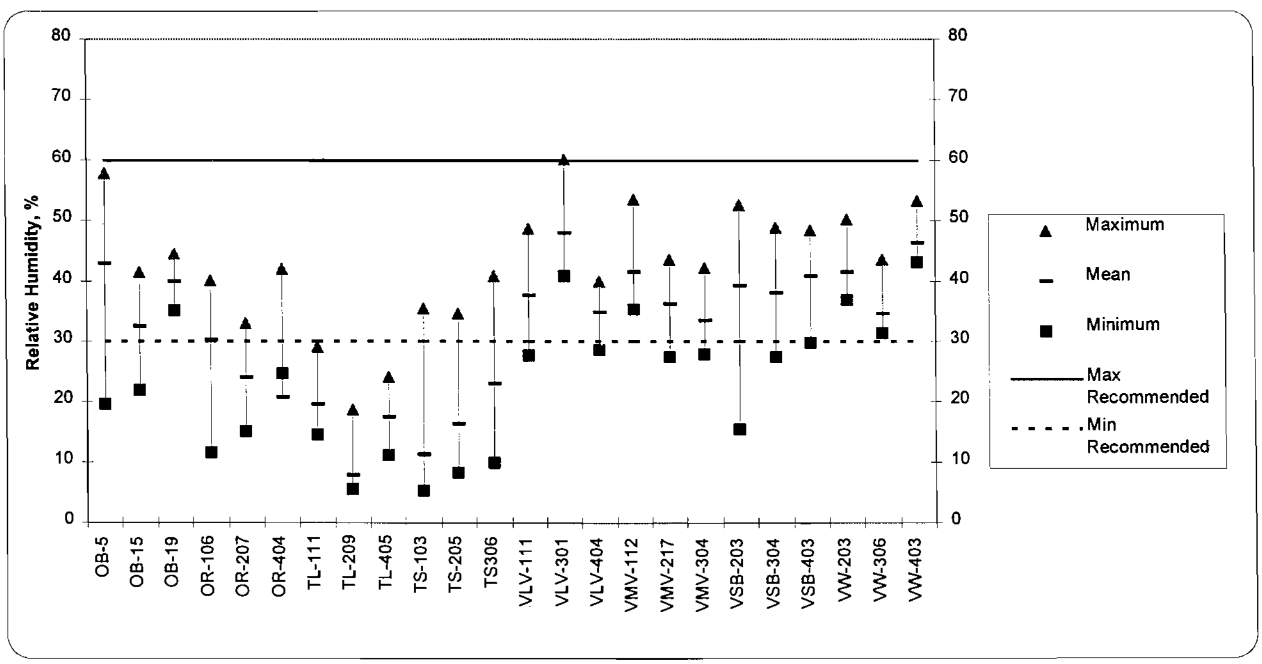


Figure 3-6: Range of variations in indoor relative humidity in test apartments.

3.3.4. Carbon Dioxide

The carbon dioxide readings were taken in three suites in each building for a period of seven to ten days using a continuous data logger. Data was collected at a 10 minutes interval. Figure 3-7 shows a range of carbon dioxide levels measured in test units.

The measured readings were compared with two Standards. The ASHRAE Standard 62-1989 stipulates that the CO_2 levels must be below 1,000 ppm for maintaining human comfort.[18] Except for the buildings located in Ottawa, the majority of other buildings had CO_2 levels substantially lower than 1,000 ppm. This graph also shows the maximum limit set by Health Canada at 3,500 ppm. In one unit (OB-15), high levels of CO_2 were measured which might be due to higher levels of occupancy and lack of ventilation and air leakage. It is also interesting to see that the mean value of CO_2 over the monitoring period exceeded the acceptable levels of 1,000 ppm while in the other 20 units, the mean values of CO_2 were substantially lower than the acceptable set value. The instantaneous measurements of outdoor CO_2 levels ranged from 230 to 425 ppm.

A comparison showed that CO_2 levels were high in those units where ventilation flow rates (corridor air, and bathroom and kitchen exhausts) were significantly low. Ventilation and air movement plays an important role in removing metabolic pollutants.

3.3.5. Carbon Monoxide

The carbon monoxide readings were taken in three suites in each building for a period of seven to ten days using a continuous data logger. Data was collected at a 10 minutes interval. Figure 3-8 shows the maximum reading of carbon monoxide level measured in test units.

The measured readings were compared with the Health Canada guidelines. The guidelines suggests a permissible exposure limit of 25 ppm for one hour period and average 11 ppm over 8 hour period. In all buildings, the maximum value of CO levels ranged from negligible to about 7 ppm.

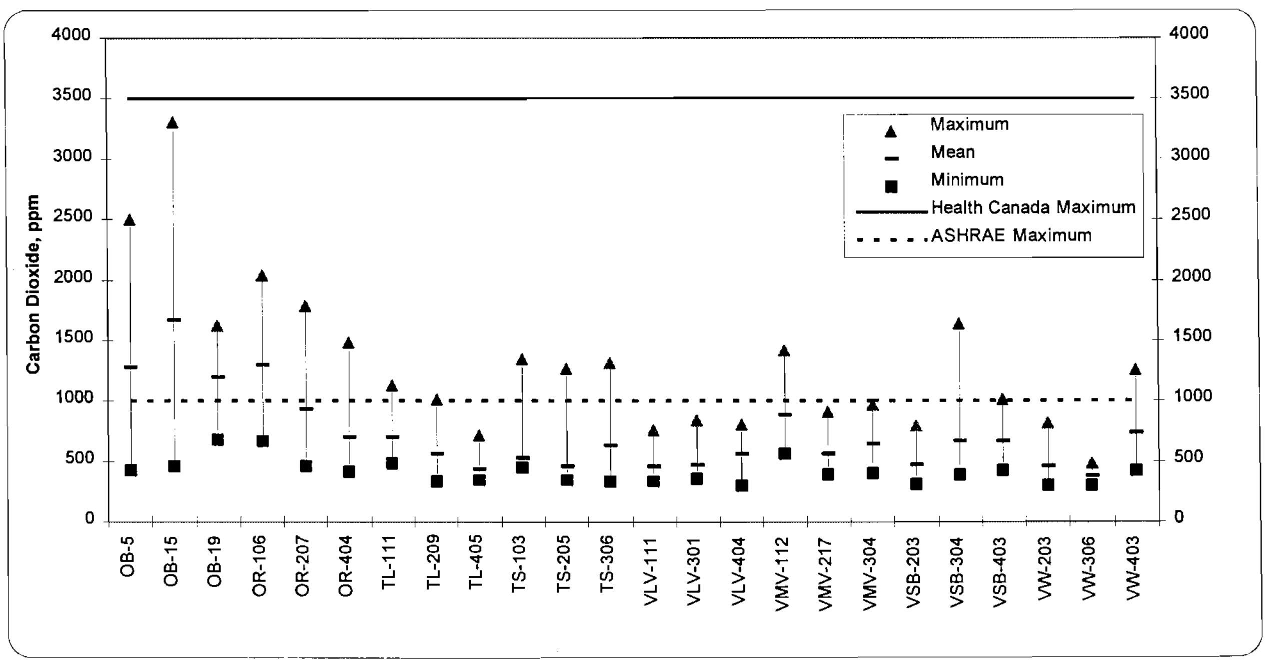


Figure 3-7: Range of variations in indoor carbon dioxide levels in test apartments.

[18] ASHRAE 1989. "Ventilation for Acceptable Indoor Air Quality," ASHRAE Standard 62-1989. Published by ASHRAE.

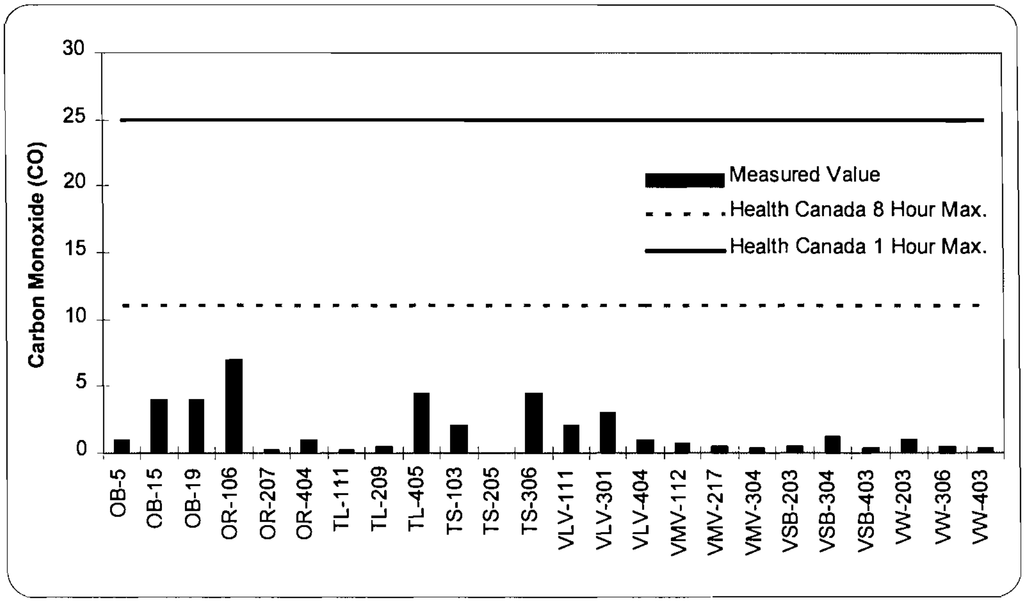


Figure 3-8: Maximum levels of carbon monoxide readings measured in test units.

3.3.6. *Formaldehyde*

Two AQR dosimeters were placed in 3 apartment units for a period of seven days in each building to measure the formaldehyde concentration. As shown in Figure 3-9, formaldehyde concentration ranged from 0.01 ppm to 0.06 ppm in the test units. The formaldehyde levels were significantly lower than acceptable upper limit of 0.05 ppm suggested by Health Canada. Health Canada guidelines also suggests an action level of 0.10 ppm at which one should implement remedial measures. In three test units, formaldehyde levels were more than 0.05 ppm. Higher values of formaldehyde were noticed in units with low ventilation flow rates.

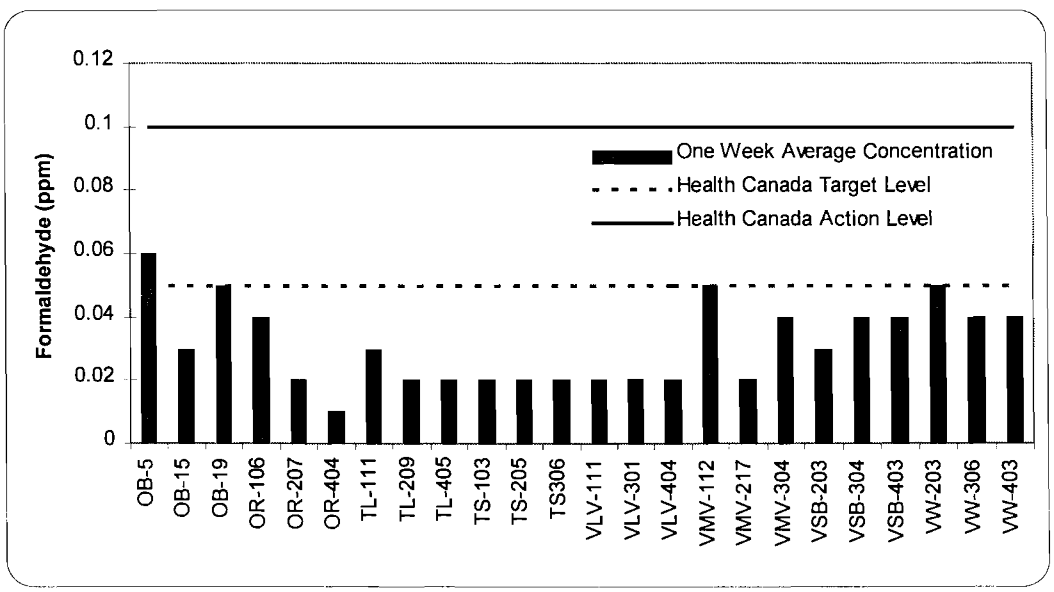


Figure 3-9: Measurements of formaldehyde concentrations in test units.

3.3.7. *Volatile Organic Compounds (VOCs)*

The VOCs were sampled in three apartment units for a period of one week in each building. The apartment in each building with the highest TVOC was chosen for further analysis. The VOC badges from these units were also analyzed to determine the concentration of the following target compounds.[19]

n-hexane	α-pinene	m-xylene	hexachloroethane
dichloromethane	tetrachloroethylene	o-xylene	p-dichlorobenzene
benzene	toluene	d-limonene	1,1,2,2-tetrachloroethane
n-decane	1,2-dichloroethane	1,3,5-trimethylbenzene	1,2,4-trichlorobenzene
trichloroethylene	ethylbenzene	m-dichlorobenzene	naphthalene
chloroform	p-xylene	pentachloroethane	

Table 3-10 and Figure 3-10 show the measurements of volatile organic compounds. As shown in the figure, the TVOC concentration ranges from almost negligible to about 0.72 mg/m^3 in apartments. As shown in the figure, the TVOC levels were significantly lower than targets set by various Standards and guidelines.

In Ottawa 'B' building TVOC testing was conducted two times. First test was conducted in April 1995 which showed the TVOC level of 2.21 mg/m^3. Subsequent testing for TVOC in April 1996 showed the TVOC value of 0.72 mg/m^3. Outdoor environmental conditions and emission rates from building materials may well have influenced the readings of TVOC.

Table 3-10: Target Volatile Organic Compounds (VOCs)

Building	Unit	Target Compound	Result (mg/m^3)
Ottawa 'B'	15	x-pinene	0.16
		d-limonene	0.47
Ottawa 'R'	404	chloroform	0.002
		benzene	0.070
		toluene	0.27
		perchloroethylene	0.001
		ethyl benzene	0.024
		m-p xylenes	0.078
		oxylenes	0.030
		styrene	0.002
		dichlorobenzene	0.001
		d-limonine	0.38
		hexane	0.071
		1,2,4 trimethylbenzene	0.026
Toronto 'L'	111	benzene	0.006
		toluene	0.015
		ethylbenzene	0.001
		m-p xylenes	0.004
		o-xylenes	0.001
		dichlorobenzene	0.013
		d-limonene	0.054
Toronto 'S'	206	all	too low for individual detection
Vancouver 'LV'	111	toluene xylenes benzenes	too low for individual detection
Vancouver 'MV'	112	all	too low for individual detection
Vancouver 'SB'	304	all	too low for individual detection
Vancouver 'W'	203	all	too low for individual detection

[19] Conversion factor mg/m^3 = atomic mass/24 * ppm

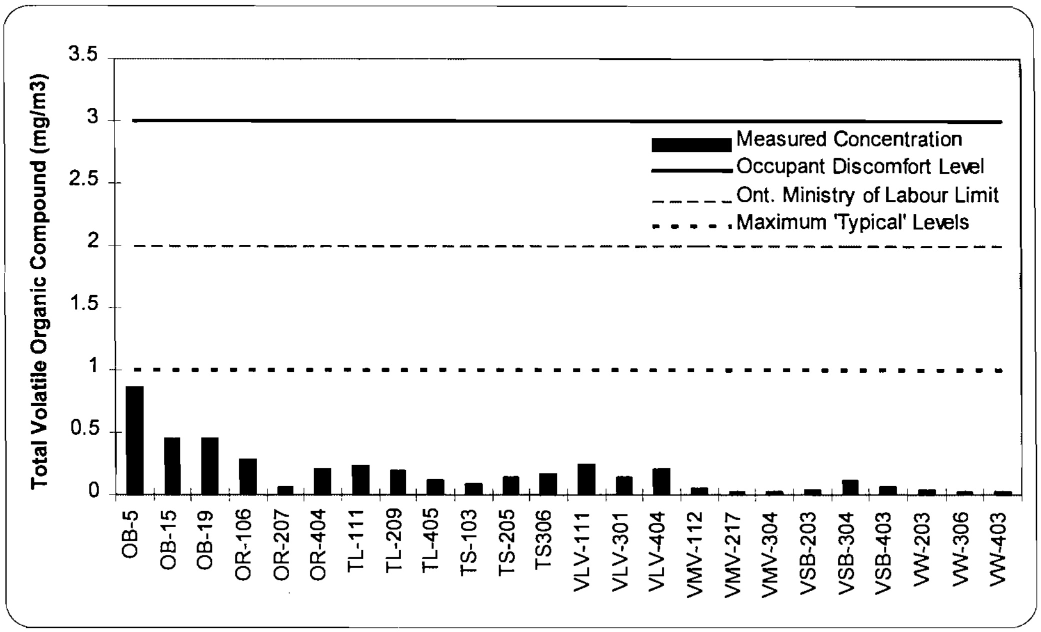


Figure 3-10: Measurements of TVOCs in test units. Maximum typical level for residential occupancy is suggested by CMHC.

3.3.8. Electromagnetic Fields (EMFs)

Instantaneous readings of electro magnetic fields were taken using the standard protocol suggested by Ontario Hydro. Measurements of EMFs were taken in the middle of each of the rooms listed in the Table 3-11 below. Note that "with" means with the suite power as found, and "without" means that the suite power was turned off.

There are no agreed set limits for EMF emissions. Ontario Hydro recommends a level up to 20 milligauss near the equipment and about 8 milligauss at 0.3 m away from the source. A recent Swedish study suggested health risks at 3 milligauss of EMF in residential occupancies. Table 3-11 shows that EMF values were much lower than 20 milligauss and few readings were more than 3 milligauss.

3.3.9. Lighting Levels

Lighting levels were measured in common areas and corridors. Table 3-12 summarizes the average levels of lighting in the building. Lighting levels were measured using a hand held light meter. The measured lighting levels were compared with the recommended good practices as defined in Ontario Hydro's Energy Manual Fundamentals[20]. The lighting levels were also consistent with OBC 1990 and 1990 NBC. Comparison showed that lighting levels were adequate in most cases. It was also observed that the outside lighting was controlled by photo-cells or time clocks in all buildings.

[20] Ontario Hydro 1987. Ontario Hydro Commercial Electric Energy Manual Fundamentals and Applications, Chapter 16, Ontario Hydro, 1987.

Table 3-11: Measurements of Electro Magnetic Field in Apartment Units.

		Living Room (milligauss)		Master Bedroom (milligauss)		Kitchen (milligauss)		Bathroom (milligauss)	
Building	Unit	with	without	with	without	with	without	with	without
Ottawa 'B'	5	1.18				1.19			
	15	1.67	1.41						
	19	4.38	3.4			3.78	3.01		
Ottawa 'R'	106	1.52		1.6		1.62			
	207	1.92	1.08					3.00	2.27
	404	1.5	0.49						
Toronto 'L'	111	1.64		1.27		4.31		8.45	
	209	1.01		0.9		1.12		1.02	
	405	0.74		0.47		1.34		0.34	
Toronto 'S'	103	2.09		2.13		2.14		2.08	
	205	2.88*		2.44		2.75		2.34	
	306	2.13		1.68		1.42		2.16	
Vancouver 'LV'	111	2.21	2.2	2.2	2.38	2.02	1.92	2.19	2.07
	301	0.22	0.25	0.2	0.27	0.26	0.19	0.34	0.27
	404	0.78	0.31	0.36	0.35	0.64	0.6	0.46	0.38
Vancouver 'MV'	112	0.71**	0.47	0.52	0.52	0.43	0.43	0.42	0.43
	217	0.39**	0.36	0.64	0.37	0.82	0.57	0.42	0.36
	304	0.34	0.33	0.33	0.35	0.46	0.31	0.29	0.33
Vancouver 'SB'	203	1.44	1.41	1.28	1.21	1.19	1.3	1.57	1.41
	304	1.05	1.06	0.88	0.81	0.76	0.74	0.47	0.58
	403	1.12	1.07	1.02	1.03	1.22	0.83	2.19	0.94
Vancouver 'W'	203	0.45	0.33	0.66	0.5	0.38	0.22	0.29	0.21
	306	0.43	0.32	0.52	0.52	0.82	0.45	0.45	0.45
	403	0.24	0.35	0.37	0.29	1.11	0.4	0.35	0.24

* Baseboard heater on ** TV on

Table 3-12: Lighting levels in apartment buildings.

Building	Lighting Level (Foot-candles)						
	Corridors	Front Lobby	Elevators	Elevator Lobbies	Stairwells	Laundry Room	Rec. Room
Ottawa 'B'	12	8	none	none	32	none	none
Ottawa 'R'	10	10	30	10	40	35	20
Toronto 'L'*	11-90		20	7-80			
Toronto 'S'	5-20	10	none	none	22	20-55	5-50
Vancouver 'LV'	2	6	20	3	50	170	
Vancouver 'MV'	1.5	6	6	1.5	12-50	50	25
Vancouver 'SB'	3	12-25	25	12	12	50	12
Vancouver 'W'	6-12	3	25	3	3-25	50	6
Good practices	**9-14**	**9-14**	**10-15**	**10-15**	**15-25**	**30-50**	**50-75**

* The lighting levels in the front lobbies, stairwells, laundry rooms and recreation rooms were not measured in Toronto 'L' since they all had large windows and the lighting levels were those of the exterior and not the installed artificial lights

conversion factor 1 foot-candle = 10 76 lux

4. ENERGY ANALYSIS

The energy consumption in each of the buildings was simulated using the DOE-2.1E program[9], and reconciled, where possible, to the billing data. The following items summarizes energy analysis procedure:

- Building Description: Input data files were prepared using the building description, field audits, and architectural and mechanical drawings. For generating the input files, buildings were described on the basis of energy flow perspective rather than from an architectural perspective. Thermal zones were defined as follows:
  - at least four external zones (one for each exposure) per floor; and
  - at least one internal zone (central core, elevators and corridors) per floor.

  The above classification of thermal zones also separated the types of heating and ventilation systems for multi-unit residential buildings.
- Field Data: The field survey provided the data on the performance of make-up air systems, and kitchen and bathroom exhaust systems. Operation schedules for the make-up air system, exhaust fans, elevators and DHW system were obtained during the site visit. Occupancy profiles were estimated based on the type and number of occupants in each building.
- Weather Data: Annual hourly weather data for the location were obtained from Atmospheric Environment Services Branch of Environment Canada.
- Utility Bills: Utility bills were obtained from building managers for a period of one to two years. Utility bills were used to determine the monthly and annual energy consumption patterns of each building.

Results from the energy simulations are provided for each test building in Appendix A.

4.1. ENERGY USE IN BUILDINGS

Utility bills were used for determining the energy use profiles in each test building. Table 4-1 shows the summary of energy use in buildings. As shown in the table, the annual total energy use ranges from 146 to 263.2 kWh/m^2 of floor space. Figure 4-1 graphically presents the comparison of energy use and energy costs for each building.

The average unit costs of electricity and natural gas are given in Table 4-2. It should be noted that the average unit cost includes the fuel supply charges, rental charges and Goods and Service Tax (GST). The average unit cost; however, do not include the payment penalty or interest charges. In effect, the cost of energy is what the building owner will pay for. The equivalent cost of natural gas is about two to four times lower than electricity costs. The difference in fuel costs affects the annual energy costs in the building. As shown in Table 4-1, the annual cost of energy used in the buildings ranges from \$6.76/m^2 to \$20.05/m^2 with an average of \$10.04/m^2.

The energy use survey included a total of 284 suites in eight buildings. The utility bills for each suite ranged from \$461 to \$1,683 per year. The average utility bill per suite was about \$746 per year based on costing data available for the year 1994.

Table 4.1: Summary of Energy Use in Mid-Rise Apartment Buildings.

	Description	Ottawa 'B'	Ottawa 'R'	Toronto 'L'	Toronto 'S'	Vancouver 'LV'	Vancouver 'MV'	Vancouver 'SB'	Vancouver 'W'	Average	Std. Deviation
1	Location	Ottawa	Ottawa	Toronto	Toronto	Vancouver	Vancouver	Vancouver	Vancouver		
2	Year of construction	1990	1991	1991	1994	1992	1993	1993	1993	1,992	1.4
3	Number of floors	3.5	4	4	3	4	3	4	4	3.7	0.5
4	Number of suites	23	35	51	17	45	45	31	36	35	12
	Utility Bills										
5	Annual electricity consumption (kWh)	244,472	654,269	348,303	51,040	256,341	247,813	206,600	230,667	279,938	172,314
6	Annual natural gas consumption (m3)	-	25,884	50,879	29,123	25,778	29,821	18,682	33,897	26,758	14,296
7	Annual energy cost ($)	18,775	58,898	39,321	9,305	20,744	23,043	18,285	21,028	26,175	15,634
8	Electricity energy use, kWh /m2	150.0	222.8	81.0	58.6	83.8	75.8	76.4	91.6	105.0	54.7
9	Fuel energy use, kWh/m2	-	40.4	89.3	160.9	69.0	100.0	69.6	107.9	79.7	47.8
10	Equivalent energy use, kWh/m2	150.0	263.2	170.3	219.5	152.8	175.8	146.0	199.5	184.6	40.7
11	$/m2	11.52	20.05	9.14	10.68	6.78	7.05	6.76	8.35	10.04	4.42
12	$/suite	816.28	1,682.80	771.00	547.35	460.98	512.07	589.84	584.11	745.55	398.06
	Heat Gains During Heating Season (Estimated with DOE-2.1E)										
13	Solar gains, kWh/m2	13.1	13.4	15.1	12.8	8.7	13.5	8.9	6.3	11.5	3.1
14	Internal gains, kWh/m2	23.0	24.5	21.4	23.7	10.1	21.7	22.3	24.3	21.4	4.7
15	Space heating, kWh/m2	64.2	102.2	91.7	106.0	77.9	88.3	51.7	57.5	79.9	20.5
16	Total heat gains, kWh/m2	100.2	140.1	128.1	142.5	96.7	123.4	83.0	88.1	112.8	23.6
	Heat Losses During Heating Season (Estimated with DOE-2.1E)										
17	Walls, kWh/m2	12.3	26.0	6.9	29.4	28.1	16.7	14.1	9.3	17.8	8.8
18	Roof, kWh/m2	5.8	14.8	4.5	11.7	6.2	6.2	4.3	7.3	7.6	3.7
19	Below grade, kWh/m2	5.7	10.9	22.2	10.1	5.4	12.6	0.8	4.9	9.1	6.6
20	Windows and doors, kWh/m2	30.7	41.8	48.9	50.5	25.2	22.2	23.2	32.2	34.3	11.3
21	Ventilation, kWh/m2	6.9	21.2	21.4	17.1	12.7	24.0	17.2	18.8	17 4	5.5
22	Air leakage, kWh/m2	39.1	25.4	24.3	23.7	19.1	41.6	23.4	15.5	26.5	9.1
23	Total heat losses, kWh/m2	100.4	140.1	128.1	142.5	96.7	123.4	83.0	88.1	112.8	23.6
	Other Energy Use Components (Percentage of annual utility bills reconciled with DOE-2.1E estimates)										
24	Space heat	42.9%	37.9%	53.8%	48.3%	50.9%	50.2%	35.4%	28.8%	43.5%	8.8%
25	DHW	25.9%	26.2%	28.4%	23.5%	20.4%	24.5%	28.4%	25.3%	25.3%	2.6%
26	Lighting	20.4%	20.1%	9.7%	11.8%	12.0%	9.4%	14.5%	20.4%	14.8%	4.8%
27	Miscellaneous	14.2%	14.2%	11.6%	14.3%	14.9%	9.9%	22.3%	24.7%	15.8%	5.1%
28	Unaccounted	-3.4%	1.6%	-3.5%	2.1%	1.8%	6.0%	-6.0%	8.0%	0.8%	4.8%
29	Total, kWh/m2	150.0	263.2	170.3	219.5	152.8	175.8	146.0	199.5	184.6	40.7
30	Total, kWh/ft2	13.9	24.4	15.8	20.4	14.2	16.3	13.6	18.5	17.2	3.8

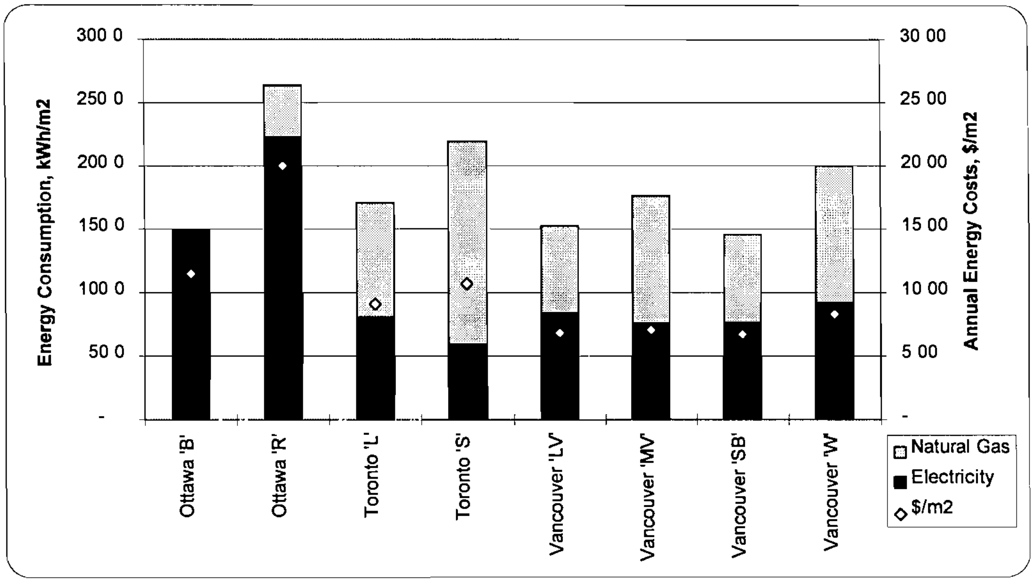


Figure 4-1: Annual energy use in mid-rise apartment buildings.

Table 4-2: Marginal cost of electricity and natural gas.

	Electricity $/kWh	Natural Gas $/kWh (equivalent)
Ottawa 'B'	0.077	-
Ottawa 'R	0.074	0.025
Toronto 'L'	0.074	0.038
Toronto 'S'	0.067	0.027
Vancouver 'LV'	0.059	0.024
Vancouver 'MV'	0.064	0.029
Vancouver 'SB'	0.072	0.018
Vancouver 'W'	0.063	0.018

4.2. ANALYSIS OF HEAT GAINS AND HEAT LOSSES DURING THE HEATING SEASON

Using the energy simulation results with DOE-2.1E, heat gains and heat losses profiles were developed for each building. The heat gain and heat loss balance includes the heating season only. The heat gains in the building includes the solar radiation; internal gains due to occupancy, lighting, hot water use and other energy consuming equipment; and auxiliary space heating to maintain the comfort conditions. Heat losses include the conductive heat losses through walls, windows, roof and below grade components; and convective heat losses associated with air leakage and ventilation in the building.

Figure 4-2 shows the heat gains during the heating season for eight test buildings. As shown in these figures, the availability of solar gains ranged from 6.3 to 15.1 kWh/m^2 of floor area depending on the orientation and window area of the building. The internal gains ranged from 10.1 to 24.5 kWh/m^2 of floor area for the sample of buildings. The auxiliary heating requirements ranged from 51.7 to 106 kWh/m^2 of floor area.

Figure 4-3 shows the total heat losses through building envelope components during the heating season. Conduction heat losses through walls, windows, doors, roof and below grade accounted for 42.4 to 101.7 kWh/m^2 of floor area. Heat losses associated with air leakage and ventilation ranged from 31.8 to 65.6 kWh/m^2 for the set of test buildings. Figure 4-4 shows a typical heat balance for a mid-rise residential building. As shown in the heat gains and losses balance, conduction losses accounted almost 61% of total heat losses and ventilation and air leakage accounted for about 39% of total losses. Auxiliary heating requirements are about 71% of the total heat gains in the building.

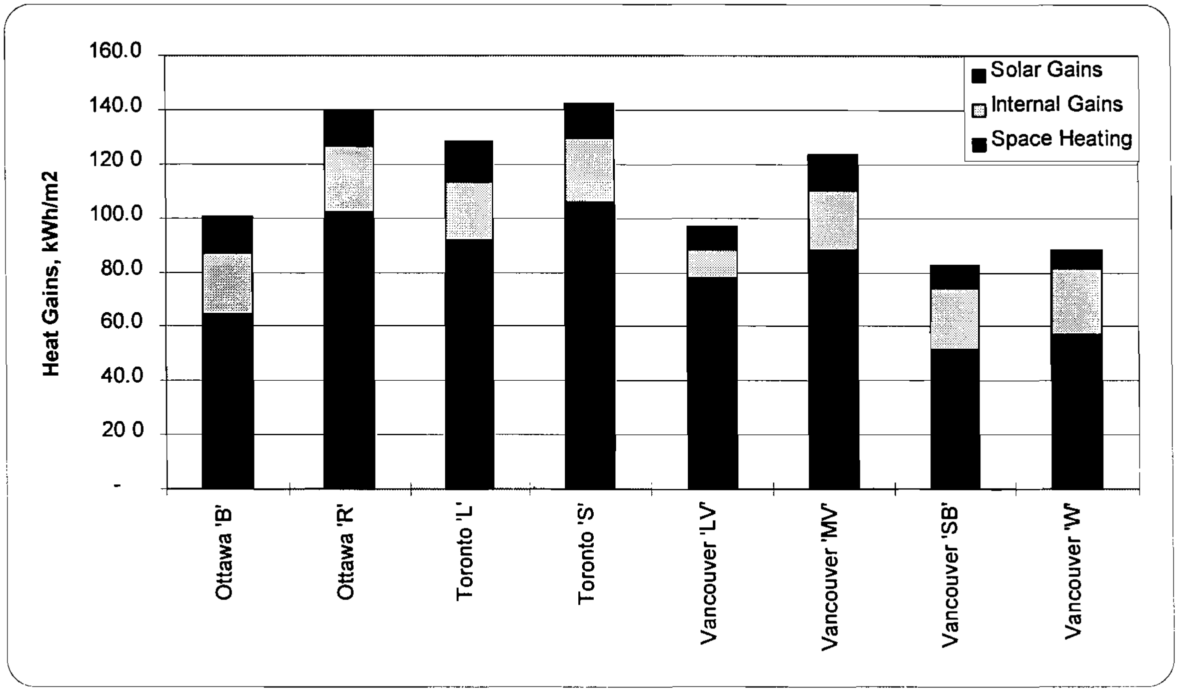


Figure 4-2: Heat gains in buildings during the heating season.

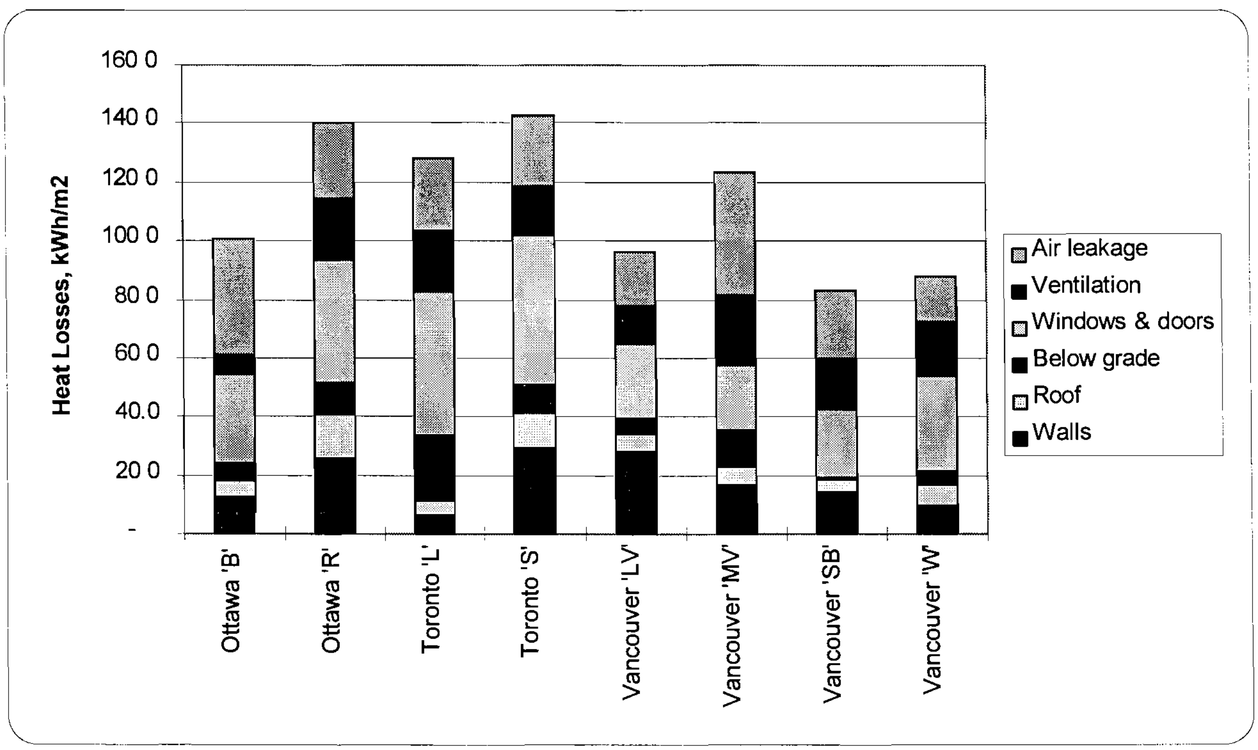


Figure 4-3. Profile of heat losses during the heating season in mid-rise residential buildings.

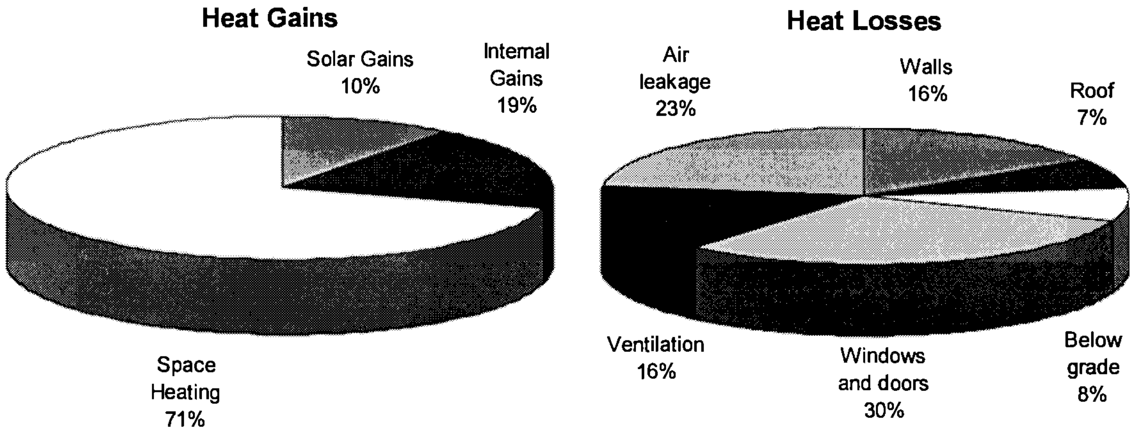


Figure 4-4: A typical balance of heat losses and heat gains in a mid-rise apartment building during the heating season.

4.3. COMPONENTS OF ENERGY USE

The DOE-2.1E simulations also provided useful evaluation of different components of annual energy use in the test buildings. Figure 4-5 shows the evaluation of various energy use components for eight test buildings.

The space heating requirement ranged from 28.8% to 53.8% of the annual energy requirements. The energy use for domestic hot water heating (includes pumping and distribution parts) ranged from 20.4% to 28.4% of the annual energy use in buildings. The lighting energy use ranged from 9.4% to 20.4% of the total energy use. The miscellaneous component which ranged from 9.9% to 24.7% included the energy used by elevators, laundry equipment, suite appliances (freezer, stove, entertainment etc.), and air conditioners.

The reconciliation of DOE-2.1E estimates and actual utility bills was also undertaken as part of the energy simulation work. The unaccounted portion showed the difference between the actual utility bills and DOE-2.1E estimates. The unaccounted portion ranged from -6% to +8% for the test buildings with an aggregate average of about 1% for the whole sample.

Figure 4-6 shows a typical profile of annual energy use in a mid-rise apartment building. As shown, the space heating and domestic hot water use in the building may account for more than 68% of the total energy use in the building. For a building, which uses natural gas for heating, the energy costs attributed to space heating and domestic hot water use may account for less than 49% of the total energy costs. The cost difference between the unit prices of natural gas and electricity should be one of the prime consideration for the type of heating equipment.

Figure 4-7 shows the annual energy costs associated with the air leakage and ventilation in test buildings. Ventilation component includes the fan energy and conditioning of the fresh outdoor air. Ventilation and air leakage costs ranged from 11% to 26% of the annual energy costs in test buildings.

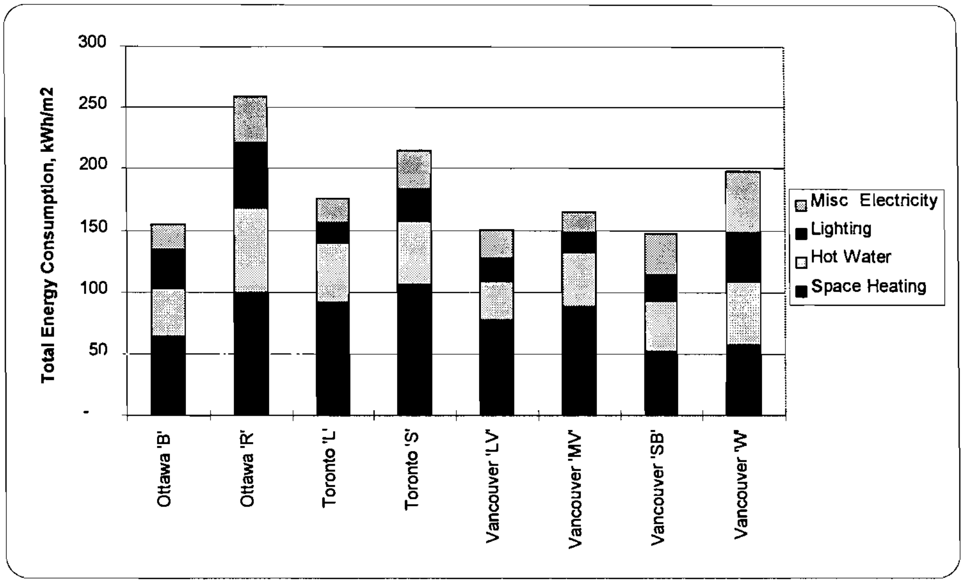
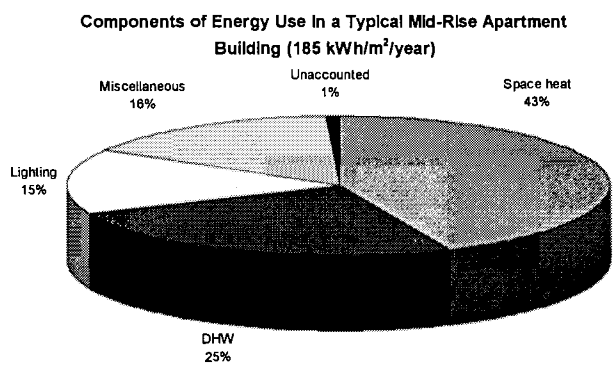


Figure 4-5: Components of annual energy use in test buildings.



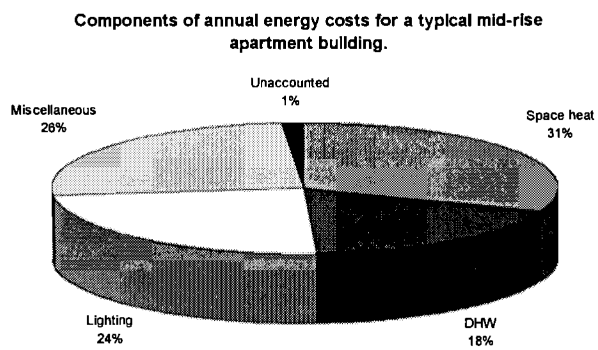


Figure 4-6: A profile of annual energy use (kWh) and energy cost ($) in a typical mid-rise apartment building.

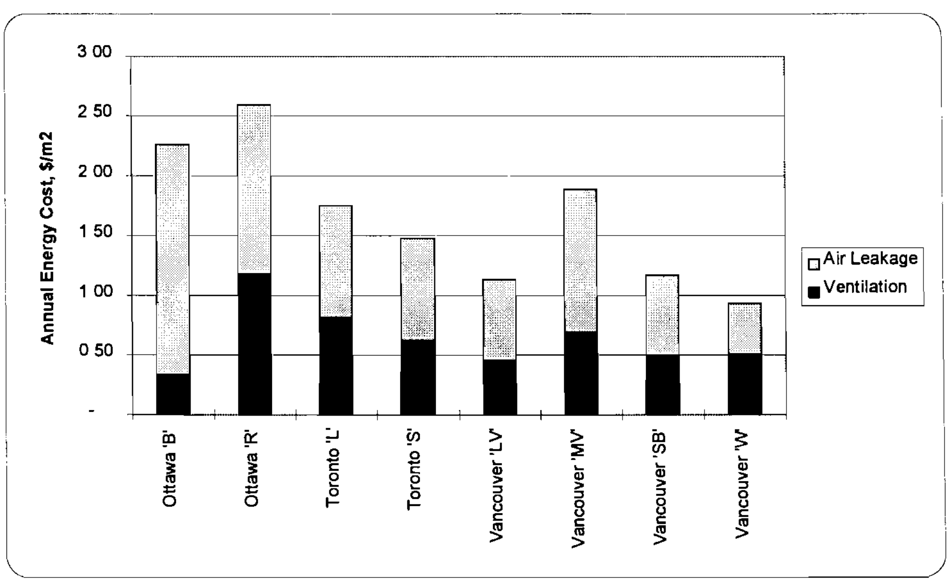


Figure 4-7: Annual energy cost attributed to air leakage and ventilation in test buildings.

5. OBSERVATIONS AND DISCUSSIONS

The test buildings were built from 1990 to 1994. Out of four Ontario buildings, 3 buildings were built as per the requirements of 1990 Ontario Building Code and one building as per the requirements of 1993 Ontario Building Code. All four Vancouver buildings were built as per the requirements of 1990 BC Building Code. One of the objective of the present study was to evaluate the 'as is' performance of the air barrier requirements and ventilation requirements necessitated by codes. Detailed evaluation of IAQ and energy use is given in preceding sections (section 3 and 4). Based on a field survey and investigations of indoor air quality and energy use of eight buildings, the following points provide general trends and operating status of the mid-rise residential buildings.

- **Air barrier:** Field surveys showed that all buildings had 6 mil polyethylene air barrier installed for walls, roof and below grade components. As per the recommendations in good design practices for air barrier system in tract building, the air leakage rate is expected to be about 0.7 to 1.6 L/s.m^2 at 75 Pa pressure difference. The airtightness tests of the eight older high-rise buildings showed that the envelope air leakage rate ranged from 2.23 to 3.60 L/s.m^2 at 75 Pa pressure difference. High air leakage through the envelope is attributed to the following:
  - poor detailing of air barrier at critical junctions such as window and wall, door and wall, wall corners, and roof and wall joints;
  - air leakage through window weatherstripping and door weatherstripping seem to be exceptionally high in several buildings thereby affecting the overall airtightness of the building shell; and
  - penetrations through building envelope are not properly sealed (in one building, electrical baseboard heater cables penetrate through the air barrier).

  For new construction of MUR buildings, the following remedial actions should be considered:
  - Architectural drawings should provide details of various critical joints and explain details with proper notes.
  - The construction trade needs proper training with regard to installation of air barriers.
  - Better quality control and inspection procedures should be followed during the construction phases.

- **Thermal and Insulation Levels:** The survey of eight buildings showed that all buildings were insulated as per local practices. Ontario buildings had insulation levels just meeting the Part IX requirements for their respective zones. It was noticed that although walls were constructed using proper levels of insulation, the placement of insulation and the framing (shell) structure created significant thermal bridging in several buildings. Due to significant thermal bridging, the effective thermal resistance of insulation was reduced substantially, in one building almost by 30%.

- **Ventilation and Air Movement:** Mechanical ventilation is provided by two systems: (1) Independent or in-suite kitchen and bathroom fans generally operated by tenant on manual control; and (2) make-up air to corridors which is then fed to the suites through the apartment door perimeter leakage.

  All buildings had kitchen and bathroom fans installed in the suites. As per the survey of tenants, about 82% occasionally use the kitchen exhaust fans while cooking, and about 41% of occupants use bathroom exhaust fans regularly. These exhaust fans should be used almost 100% of time when the kitchen and bathrooms are being used. Lower and irregular use of these exhaust fans can create higher humidity in the building, affect the occupant comfort and also cause window condensation and associated mold growth problems.

Except one building (Ottawa 'B'), all buildings have a dedicated make-up air system. Review of the equipment and distribution system for make-up air ventilation showed that these systems were designed as per the current practices and have the capability to provide ventilation in the building as specified by CSA F-326 for suites and ASHRAE 62-1989 for corridors. In most cases, the installed equipment capacity exceeded by 10% to 25% of the design requirements. The performance measurements showed that the make-up air system delivered 40% to 100% of the installed capacity. In most cases, corridors received some amount of ventilation air; however, not adequate based on applicable codes and standards.

Air supply to suites from the apartment doorway was also measured in all buildings. A sample of three suites were selected in each building to evaluate the amount of air entering the suite from the corridor. Except in three buildings (Ottawa 'R', Toronto 'L' and Toronto 'S'), suite doors leading to the corridor were weatherstripped in all buildings thus allowing negligible quantity of ventilation air from the corridor to the suite. In the other three buildings, the ventilation flow rate was about 15 to 20 L/s, well below the CSA F-326 requirements of 20 to 30 L/s per suite. Air change rate tests in about 12 units in eight buildings showed that the mechanical ventilation rates were well below the CSA F-326 requirements.

From the above observations, we found that these mid-rise residential buildings had the necessary ventilation and exhaust equipment installed to meet the code requirements. However, the performance evaluation showed that these exhaust and ventilation systems could not be expected to reliably ventilate individual suites in the buildings. Make-up air systems delivered fresh air to the corridors which eventually escaped to outside due to lack of proper transfer mechanism between the corridor and the suites. The under-performance of ventilation systems also seem to be associated with high levels of relative humidity, high levels of carbon dioxide, window condensation and mold growth in several buildings.

- **Occupant Comfort:** A survey of occupants provided information on the general operating conditions in the test buildings. Occupant surveys showed that a significant portion of tenants did not find the indoor air quality acceptable. Our observation is based on the definition of 'acceptable comfort level.' According to ASHRAE Standard 55, the acceptable comfort level is defined on the basis of acceptance of 80% of total occupants. Anything below this level of 'comfort acceptance' is considered unsatisfactory. The major causes for occupant discomfort are mainly related to poor indoor air movement and lack of ventilation in living area (suites). It is also notable that about one in six occupants reported that, in their opinion, their health problems are due to the poor air quality in the building.

- **Energy Consumption Profiles:** Energy analysis of eight mid-rise residential buildings showed that the purchased total energy consumption ranged from 146 to 263 kWh/m^2 with an average of 185 ± 41 kWh/m^2 of floor space per year. In contrast, the energy consumption for high-rise residential buildings ranged from 152 to 309 kWh/m^2 with an average of 222 ± 60 kWh/m^2 of floor space per year[21]. A survey of about 200 single family houses built during 1989-93 showed that the average energy consumption was 140 to 220 kWh/m^2 per year[22].

  Figure 5-1 shows the comparison of energy consumption index, based on kWh/degree-day/m^2 of the floor space, for mid-rise, high-rise and single family housing stock. As shown in the figure, the mean value of the energy consumption for a high-rise and mid-rise building is almost the same. Compared to a single family houses, the mid-rise residential units had about 10% less energy consumption per unit area despite the fact that mid-rise units had significantly less exposed surface area than single-family houses.

[21] CMHC 1996 Energy Audits of High-Rise Residential Buildings Report prepared by Scanada Consultants Limited for the Research Division of Canada Mortgage and Housing Corporation, Ottawa

[22] NRCan 1997 Airtightness and Energy Efficiency of New Conventional and R-2000 Housing in Canada Report prepared by Tom Hamlin and John Gusdorf, Natural Resources Canada

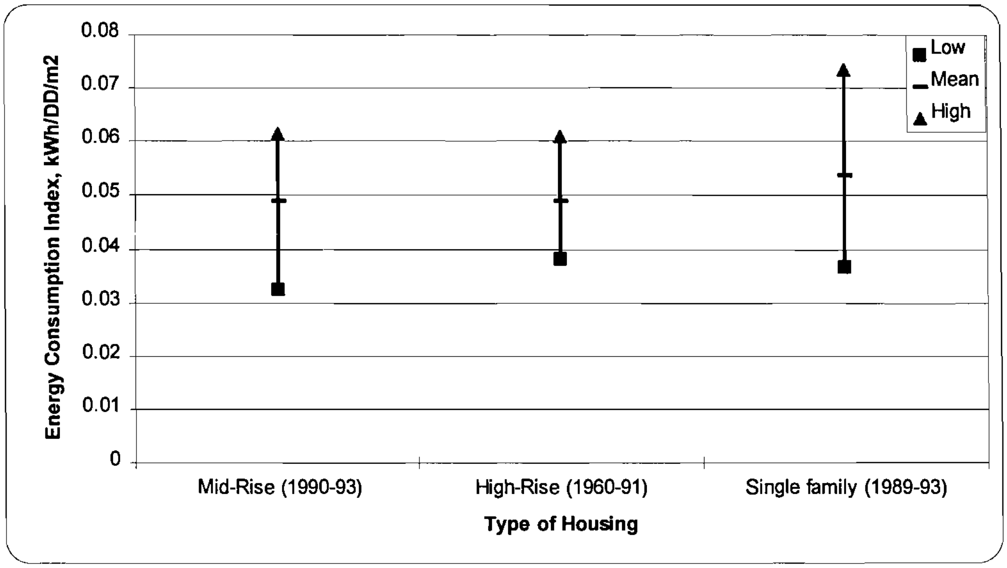


Figure 5-1: Comparison of energy consumption index for different types of housing.

- **Lessons Learned from the Field Survey:** The following summarizes the project team's experiences with regard to conducting detailed field investigations of residential buildings:
  - To be successful, a field survey requires full cooperation from building owners, operators and, most importantly, tenants. During the survey, the project team was able to get full cooperation from building owners and operators and in most cases from tenants. It was helpful to keep open communication with all involved and explanations to tenants regarding the project goals.
  - The airtightness testing using the multiple blower doors required significant amount of preparation and tenant cooperation.
  - One to one discussion with tenants and help of the building owners assisted in high return of occupant surveys. To be successful in conducting the survey, one must design the questions in simple format without being too intrusive on the personal information.
  - Indoor air quality testing using the continuous dataloggers provide operating insights. However, this option is relatively costly due to the sophisticated equipment.
  - Energy analysis was undertaken using DOE-2.1E hourly energy simulation program. In retrospect, this model requires significant amount of building information, layouts for HVAC systems and operating schedules. The simulation of energy flows seems to be insightful and provides detailed evaluation of energy use in the building. It should be noted that it required a significant amount of effort and time to undertake the energy simulation task. It took more than five person days to prepare input for the simulation and about four days to reconcile the results of energy analysis with actual metered utility bills. This can be translated as about $4,500 in efforts per building for an experienced user of the energy analysis program. Other simple and, of course, less costly methods should be evaluated to perform energy analysis of apartment buildings.
  - Overall, the field survey and energy analyses provided significant new insights into the mid-rise apartment buildings. This should help in future design, construction and commissioning of buildings. Further work is needed to develop design criteria, construction details, effective ventilation systems, quality control and commissioning procedures and, above all, a comprehensive guidelines for interweaving occupant comfort and energy efficiency in mid-rise residential buildings.

6. CONCLUSIONS

The purpose of the project was to evaluate indoor air quality and energy consumption of new mid-rise residential buildings. The research plan included the development of test and evaluation protocols for indoor environment parameters, energy consumption patterns and ventilation system performance parameters for mid-rise buildings. As part of the field work, a total of eight buildings were chosen for detailed evaluation; four buildings in Vancouver, two in Ottawa and two in Toronto. All the buildings were built in the last five years (1990 or later) to reflect current design and construction practices. The detailed evaluation of eight mid-rise residential buildings showed the following trends:

Air Leakage and Ventilation Performance:

- The airtightness of the building shell ranged from 2.23 L/s.m^2 to 3.60 L/s.m^2 at 75 Pa pressure difference. The wall corners, roof/wall joints, window and wall joints, balcony door frame and wall joints, basement/ground floor connections, and window and door weatherstripping seem to be the cause for poor airtightness in several of the test buildings.
- The air change rate tests using the passive sampling devices showed that the mechanical ventilation accounted for 0.1 to 0.67 air changes per hour in occupied suites. In several buildings, the estimated mechanical ventilation rate was substantially lower than the required rate of 0.30 air changes per hour as per CSA Standard F-326.
- All except one Ottawa building have a corridor make-up air ventilation system. The installed capacity of these systems met or exceeded the ventilation requirements set by ASHRAE Standard 62-1989 which was about 20 to 80 L/s per suite. Measured air flow rates for the corridor ventilation system ranged from 55% to 99% of the installed ventilation capacity.
- The corridor ventilation air entering the suite through the door was negligible in five of the eight buildings due to weatherstripping of the suite/corridor entry door. Ventilation air entering the suite through the corridor in the other three buildings ranged from 13 to 27 L/s. The supply of ventilation air in suites fall short off the requirements set by CSA F-326 which ranged from 20 to 35 L/s per suite.
- All suites had bathroom exhaust and kitchen exhaust fans. In all buildings, the installed capacity of bathroom and kitchen exhaust fans met the requirements set by CSA F-326. However, the measured air flow rates of kitchen and bathroom exhaust fans showed that most bathroom fans exhausted 30% to 85% of their rated capacity. The performance of kitchen fans was slightly better. Kitchen fans exhausted 50% to 90% of their rated capacity.
- Occupant surveys showed that about 82% occupants regularly used kitchen exhaust fans while 41% of occupants regularly used bathroom exhaust fans.
- From the above observations, we found that mid-rise residential buildings had the necessary ventilation and exhaust equipment installed to meet the code requirements. However, the performance evaluation showed that these exhaust and ventilation systems did not function to the required level and generated significantly low air movement in the building. Make-up air system provided the fresh air in corridors which eventually dumped to outside due to a lack of proper transfer mechanism between the corridor and the suites. The under-performance of ventilation systems also seem to cause high levels of relative humidity, high levels of carbon dioxide, window condensation and mold growth in several buildings. This problem demonstrates short comings in conventional approaches to mechanical ventilation in MURBs. The problem is two fold: (1) Failure to provide adequate ventilation distribution at the design stage; and (2) failure to anticipate that occupants do not like, noise, light and odour transfer

around suite doors. There is a need to revisit and rethink the whole issue of MURB ventilation systems.

Indoor Environment:

- Occupant surveys reported that about 16% of tenants feel that they suffer from health problems due to poor indoor air quality in some buildings. About 39% of tenants complained about window condensation; 14% of occupants complained about mold growth in their suites; and only 57% of occupants felt that the quality of indoor air was acceptable in their buildings.
- In several buildings, relative humidity and carbon dioxide levels exceeded the normal acceptable limits. These buildings also had insufficient ventilation and air movement in the suites. Occupant complaints are also high. The occupant complaints in these building seem to be due to improper and/or lack of adequate ventilation and air distribution.
- The emissions of formaldehyde and VOCs from building materials were substantially low, and within acceptable limits in all buildings.
- Field survey also showed that the electromagnetic field were much lower than 8 milligauss in all test units. Ontario Hydro recommends a level up to 20 milligauss near the equipment and about 8 milligauss at 0.3 m away from the source.
- Lighting levels in common areas of a mid-rise apartment building generally met the requirements set by good practices.

Energy Use in Buildings:

- The purchased energy in mid-rise buildings ranged from 146 to 263 kWh/m^2 of floor area per year. The annual energy cost ranged from $\$6.76/m^2$ to $\$20.05/m^2$ with an average of about $\$10/m^2$. The utility bill for each suite ranged from $461 to $1,683 per year. The average utility bill per suite was about $746 per year based on costing data available for the year 1994.
- The analysis of heat gains during the heating season showed that solar gains contributed about 10% (11.5 ± 3.1 kWh/m^2) of space heating requirements while the internal gains accounted for 19% (21.4 ± 4.7 kWh/m^2) of the space heating needs. The purchased space heating energy requirements was about 112.8 ± 23.6 kWh/m^2.
- The heat loss components during the heating season were as follows: walls accounted for 16%; roof at 7%; below grade losses at 8%; windows and doors at 30%; air leakage at 23% and the mechanical ventilation at 16% of total heat losses.
- Energy balance analysis showed that for eight test buildings the energy use was as follows:
  - purchased energy ranged from 146 to 263 kWh/m^2 and average of 184.6 ± 40.7 kWh/m^2.
  - space heating accounted for 43.5% ± 8.8%;
  - domestic hot water use accounted for 25.3% ± 2.6%;
  - lighting accounted for 14.8% ± 4.8%;
  - miscellaneous energy use (suite appliances, air-conditioning and other equipment) accounted for 15.8% ± 5.1%.
- Comparison showed that the mean value of the energy consumption for a high-rise and mid-rise building is almost the same. Compared to a single family housing, the mid-rise residential units had about 10% less energy consumption per unit area despite the fact that mid-rise units had significantly less exposed surface area than single-family houses.

The multi-unit residential buildings are as energy intensive as single family houses despite their lower volume/surface area ratios, central systems, and high occupancy densities. Future research and application work must be directed to improve the energy and indoor environmental performance of multi-unit residential buildings.

Building Reports for the Field Survey of IAQ & Energy in Mid-Rise Multi-Unit Apartments

Appendix A

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November, 97

Appendix A-1: Ottawa 'B' Building

Building Report

ENERGY USE AND INDOOR AIR QUALITY IN MID-RISE APARTMENT BUILDINGS

Field Investigation and Energy Analysis Report

Appendix A-1: Ottawa 'B' Building

1. FIELD SURVEY

The subject building is a wood framed 3-storey walk-up apartment building with raised basement located in Ottawa. It is owned and operated by Communityworks Non-Profit Housing Corporation. The building construction began in 1989 and was commissioned in early months of 1990. By 1992, the building was fully occupied and all systems were satisfactorily operating. The building is surrounded by low-rise residential buildings. The building was fabricated from factory-built modules which were assembled at the site. At the time of the field survey, the building was fully occupied. As part of the project, a detailed field survey was undertaken and an inventory of energy consuming equipment and systems was prepared. The field survey included the data collection of building and systems information required for hourly energy simulation using the DOE-2.1E. The indoor environment survey was conducted using test protocols which are described in Appendix B.

The following briefly describes various building characteristics:

- **Building Layout:** This is a north-east axis building with a major portion of windows facing north-east and south-west. The main entrance is located in the north-west direction. The main entry door is between the second level and the first level (basement). Access to the basement level suites is also provided along the side and back doors and through individual suite patio doors.

  With a footprint area of 411.97 m^2, the total floor area of the building is 1,629 m^2. There are 23 apartments consisting of the following types of suites:

  - 12 one-bedroom units with approximately 43.3 m^2 of floor area (two layouts); and
  - 11 two-bedroom units with approximately 62.6 m^2 of floor area (one layout).

  Common areas and their approximate sizes include a laundry room (10 m^2), an electrical room (4 m^2), a janitor's room (2 m^2), a common room (20 m^2) and a storage room (17 m^2), all in the basement. The total area of common spaces, not including corridors and lobbies, is approximately 53 m^2.

  According to the building superintendent, all suites are occupied for an approximate occupancy of 32 adults and 11 children.

- **Building Envelope:** This is a 3 storey wood framed apartment building. The exterior walls consist of 2x6 studs with R-20 (RSI 3.52) fiberglass batt insulation. Interior finishing is with 12 mm gypsum wallboards. Field inspections confirmed that the building has 6 mil poly air barrier as per the code requirements specified in OBC 1990. The wood studs cover approximately 15% of the area. The effective thermal resistance of the wall assembly was estimated to be about RSI 2.64.[1]

[1] The effective thermal resistance of the envelope assembly was determined using the DOE-2 1E program's material and component library.

The roof structure consists of 2x10 joists with R-32 (RSI 5.63) loose glass fiber insulation. The attic space is vented with ridge vents. The effective thermal resistance of the roof assembly was estimated to be about RSI 4.54.

There are several sizes of windows in the building. About half number of windows are double-glazed picture windows with thermally broken aluminum framing. The other half are vertical single hung windows. The field survey showed that the weatherstripping on theses windows was in pretty good shape. It was also reported by the superintendent that some tenants, particularly on top floor, keep their slider windows slightly open even during winter months.

The basement level of the building is completely drywalled from inside. The below grade concrete walls are 200 mm thick and have been insulated using the interior placement of R-12 batts. The insulation only extends 60 centimeter below grade.

Some signs of moisture or mold damage were observed in the accessible areas of the building. Window condensation was reported during the cold winter months in most units.

- **Space Heating System:** The suite space heating system consists of perimeter electric baseboards. Each electric baseboard is controlled by a line-voltage thermostat located in the centre of a room. Most baseboard heaters are located below windows.

  There is no make-up air system in the building. In the basement, there is a corridor exhaust fan which can be manually operated.

- **Domestic Hot Water System:** Each suite has an individual (unitary) electric hot water tank. The hot water tank capacity is about 50 US gallons or 189 L. The nameplate rating of each heater is about 3.8 kW. The hot water temperature is set at around 60 °C (140 °F).

- **Ventilation Systems and Strategies:** Each suite has a bathroom exhaust fan and a kitchen hood fan. These fans are operated manually. There is no dedicated make-up air ventilation system in the building.

- **Lighting System:** The corridor and common area lighting system includes energy efficient compact fluorescent lamps. In each suite, tenants use the conventional lamps and high intensity lighting fixtures. The exterior lighting system uses energy-efficient fixtures.

- **Appliances and Other Systems:** Each suite has four major appliances such as stoves, refrigerator, dishwasher and microwave. Most suites have one television set and a stereo system. It was found that some suites are loaded with electronic entertainment gadgets and even exercise equipment.

- **Metering:** Each suite is individually metered for the electricity use and bills are paid by tenants. The common area and central services, such as water and sewer, are metered on bulk rates and bills are paid by the building owners.

2. AIR LEAKAGE AND VENTILATION SYSTEMS

2.1. AIR LEAKAGE TEST

The air leakage characteristics of the building envelope was determined using the whole building airtightness tests. The whole building airtightness tests were conducted using the test protocol

developed by National Research Council for CMHC[2]. The airtightness test results were evaluated using the analytical procedures described in the CGSB Standard 149.10.[3]

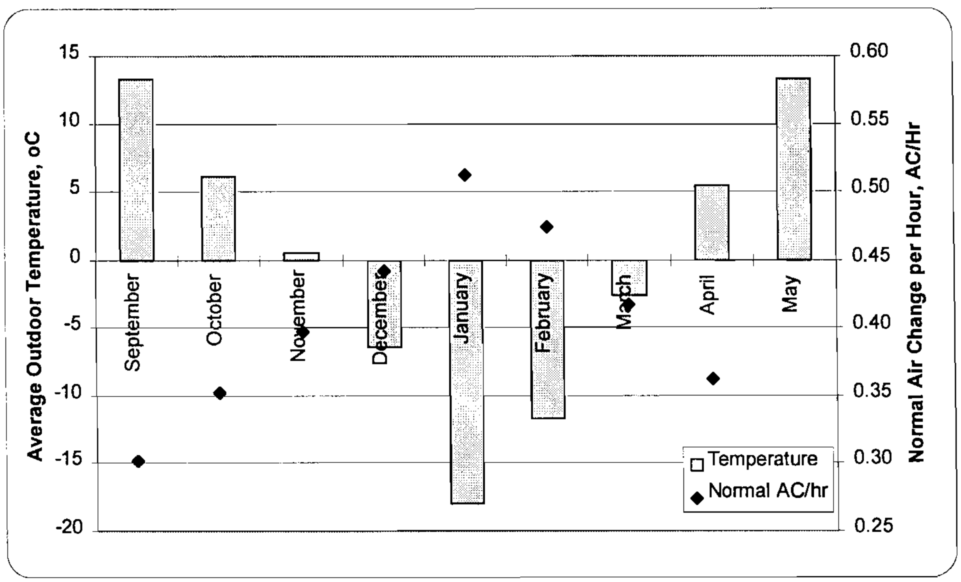
For conducting the airtightness test, three blower doors were setup in the building. The airtightness characteristics were as follows:

Table 1: Air leakage characteristics of the test building.

C, L/(s.Pa^n)	199.76	L/(sPa^n)
n	0.623	
ACH at ΔP of 50 Pa	2.17	ac/hr
ELA at ΔP 10 Pa	3,369	cm^2
Airtightness	1.798	L/sm^2 at 50 Pa
	2.314	L/sm^2 at 75 Pa

Based on the above data, air leakage control assessment procedure was used to determine the natural air leakage rates for the building. These natural air change rates were used in DOE-2.1E to determine the air leakage related heat losses. Figure 1 shows a monthly average profile of the natural air leakage rates.

Figure 1: Estimated values of natural air change rate in the building.



2.2. AIR CHANGE RATE TEST

The air change rate was determined in three units using the passive sampling devices (PFT) for a period of one week. Table 2 shows the normal air change rate measured during the one week period. The air change rate includes effects of both the natural air change due to the air leakage, air movement between zones and the mechanical ventilation in the building. It should be noted that the windows in Unit 5 and 15 were closed during the testing; however, the occupant in Unit 19 kept windows slightly opened during the test (although it was requested not to do so).

[2] CMHC 1990. **Establishing the protocols for measuring air leakage and air flow patterns in high-rise apartment buildings.** Prepared by R.J. Magee and C.Y. Shaw of IRC/NRC for CMHC, Ottawa.

[3] CGSB 1988. **CGSB Standard 149.10 (new draft - 1994) — Determination of Airtightness of Building Envelopes by the Fan Depressurization Method**, Canadian General Standards Board, Ottawa, Ontario.

Table 2: Air change rate determined using the PFT sampling.

Building	Unit	Result (ACH)
Ottawa 'B'	5	0.75
	15	1.10
	19	2.04

2.3. CORRIDOR MAKE-UP AIR SYSTEM

The purpose of the measurements of the corridor make-up air flows were to determine the performance of make-up air ventilation system. In this building, there was no dedicated mechanical ventilation system for corridor make-up air.

The air supply around the apartment door was found to be negligible. It should be noted that the apartment doors were weather-stripped as built from the pre-fab process.

2.4. KITCHEN AND BATHROOM EXHAUST FANS

The air flow rates were measured for kitchen and bathroom exhaust fans in the test units. As shown in Table 3, the kitchen and bathroom fans significantly under performed. The fan ratings showed that the bathroom fan was designed to provide 25 L/s (50 CFM) and the kitchen fan to provide 40 L/s (80 CFM). The reason for the under performance of these fans was not investigated due to the scope and nature of the present study. We suspect that the fan dampers were not properly configured during the installation.

Table 3: Air flow measurements of kitchen and bathroom fans.

		Kitchen		Bathroom
Building	Unit	Flow (High) (L/s)	Flow (Low) L/s	Flow (L/s)
Ottawa 'B'	5	6	n/a	7
	15	8	n/a	6
	19	9.5	n/a	7.5

3. INDOOR ENVIRONMENT PARAMETERS

Indoor air quality tests were conducted in three apartment units: Apartment 5 which is located in the basement, Apartment 15 which is located on the second floor, and Apartment 19 which is located on the third (top) floor.

3.1. OCCUPANT SURVEY

A questionnaire was distributed to each tenant in the building. Questions were designed to determine the opinions of tenants with regard to the performance of the building and status of the indoor air quality. The sample questionnaire, both in English and French, is provided in Appendix B. Questions pertained to:

- the performance of the building in terms of indoor air quality, odour and moisture control;
- the use of the building including the presence of pets and smokers, and time spent at home; and
- general health including identification of asthma and allergies.

The survey questionnaire was distributed to all 23 apartments. Completed survey forms were returned by 11 tenants. The response rate was about 48%.

The number of tenants occupying each suite was between 1 and 4, with an average of 1.6. There was a large percentage of respondents who were dissatisfied with the air quality in the building. Almost three quarters felt the indoor temperature was inconsistent; 64% felt the air was either too stuffy or drafty; more than three quarters felt that the indoor air was too humid, more so in the summer than in the winter. About 91% of the respondents reported window condensation in the winter and more than half reported mold in their unit. More than 91% complained of disagreeable odours, including mold, cleaning agents, cigarette smoke, car exhaust, and, most frequently cooking. Almost half the respondents reported health problems that they attributed to the building, all of whom also reported disagreeable odours. However, it is not clear what types of health problems tenants have attributed to the building.

3.2. INDOOR AIR TEMPERATURE

Indoor air temperatures were measured in three suites for a period of one week beginning on April 4, 1995 to April 11, 1995 using a continuous data logger. Data was collected at a 10 minutes interval.

Figure 2 shows a typical profile of the indoor air temperature in an occupied unit. Figure 3 shows the histogram of the measured temperature readings in the building. As shown, more than 50% of the time, in this unit, the indoor air temperature remained below 19 °C.

The measurements in three units can be summarized as follows:

- The highest recorded mean temperature was in the apartment located in the basement level and the lowest mean temperature was on the second floor level apartment.
- Mean temperatures were between 19.0 and 24.5 °C.
- The maximum temperature recorded was 27.0 °C and the minimum was 17.4 °C, a difference of 9.6 °C. The differences in temperature between the recorded maximum and the recorded minimum in each apartment were 7.5, 4.2 and 5 °C. The apartment with the highest maximum was also the apartment with the highest recorded minimum; likewise, the apartment with the lowest recorded maximum was also the apartment with the lowest recorded minimum.
- Temperatures in apartment 5 were fairly consistent between 23 and 25 °C, with most of them between 23.5 and 24.5 °C. Temperatures in apartment 15 were mostly between 18.5 and 19.5, with daily variations typically between 2 and 2.5 °C. Temperatures in apartment 19 varied between approximately 18.9 °C and 23.8 °C. At the beginning of the monitoring period temperatures were generally about 20 °C, while towards the end of the monitoring period they were closer to 22 °C.

From the above measured data, it is shown that the average temperature in the building remained at around 20 °C. The outdoor conditions did affect the indoor temperatures. During the sunny days, the indoor temperature was about 2.5 °C higher than the nighttime values.

Figure 2: Profile of indoor air temperature in a test suite.

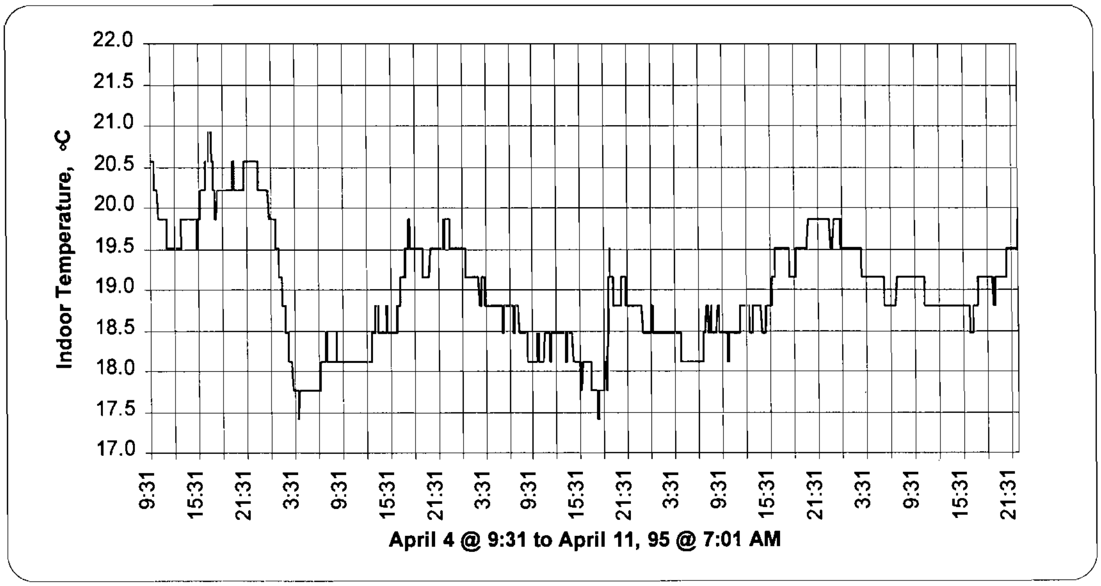
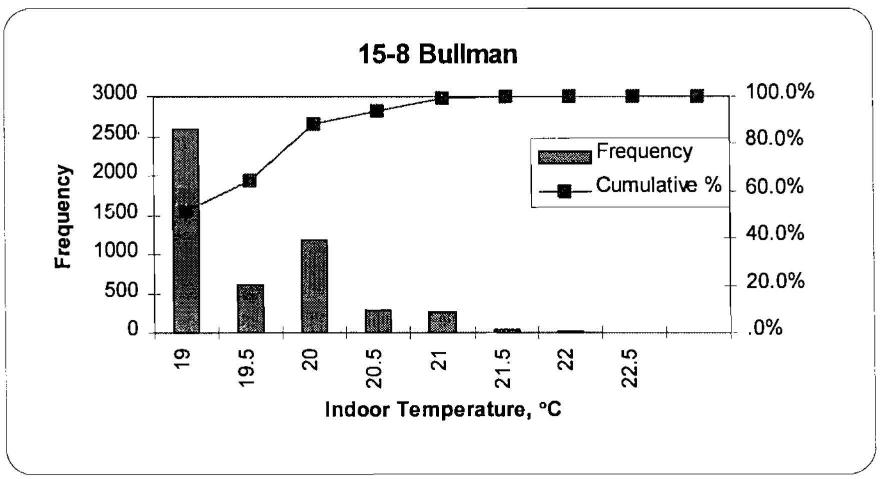


Figure 3: Frequency distribution of indoor air temperature in the test suite.



3.3. RELATIVE HUMIDITY

The relative humidity readings were taken in three suites for a period of one week beginning on April 4, 1995 to April 11, 1995 using a continuous data logger. Data was collected at a 10 minutes interval. Figure 4 shows a typical profile of the indoor relative humidity in an occupied unit. Figure 5 shows the histogram of the measured relative humidity readings in the building. As shown, more than 80% of the time, in this unit, the indoor relative humidity remained within 30 to 40% range.

The measurements in three units can be summarized as follows:

- The highest mean RH was in the lowest apartment and the lowest mean RH was in the middle apartment.
- Mean RH were between 32.6 and 42.9%.

- The maximum RH recorded was 57.8% and the minimum was 19.5%, a difference of 38.3%. The differences in RH between the recorded maximum and the recorded minimum in each apartment were 38.3, 19.6 and 9.5 %. The apartment with the highest maximum was also the apartment with the lowest recorded minimum.

From the above measured data, it is shown that the average relative humidity in the building ranged from about 20% to 60% with an overall average of about 40%. At the time of the monitoring, this level of relative humidity is acceptable for maintaining the occupant comfort.

3.4. CARBON DIOXIDE

The carbon dioxide readings were taken in three suites for a period of one week beginning on April 4, 1995 to April 11, 1995 using a continuous data logger. Data was collected at a 10 minutes interval. Figure 6 shows a typical profile of the carbon dioxide in an occupied unit. Figure 7 shows the histogram of the measured carbon dioxide readings in the building. As shown, more than 80% of the time, in this test unit, the carbon dioxide levels remained above 1,000 ppm. The average CO_2 levels were about 1,400 ppm significantly higher than recommended levels of about 1,000 ppm.

Figure 4: Profile of indoor relative humidity in a test suite.

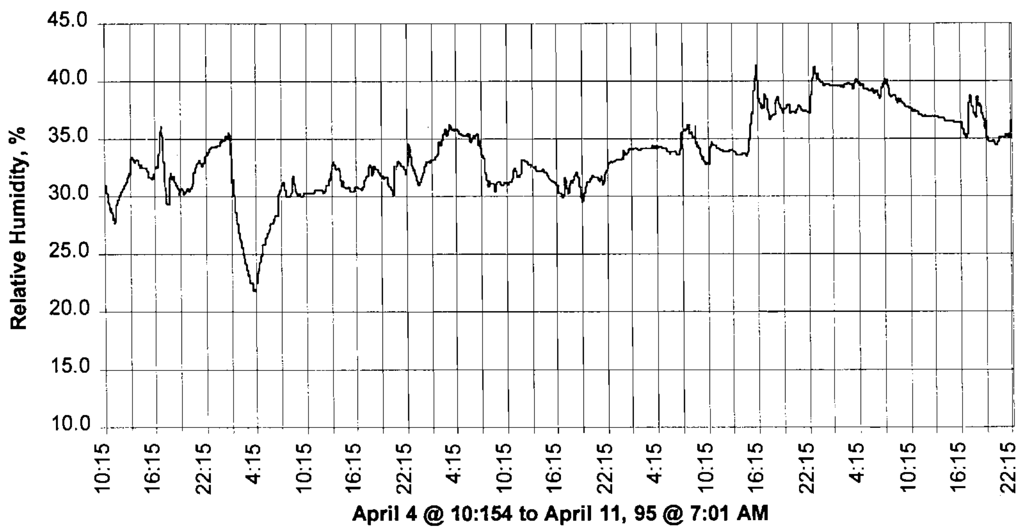
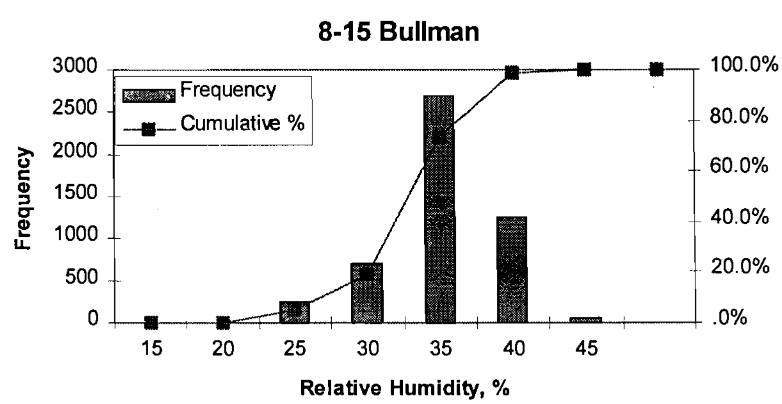


Figure 5: Frequency distribution of indoor relative humidity in the test suite.



The daily variation in CO_2 in apartment 5 generally hovered around 1,000 ppm, with a peak as high as 1,800 ppm. The daily variation in CO_2 in apartment 15 was generally about 1,400 ppm with a recorded high of 2,200 ppm. The daily range of CO_2 in apartment 19 was generally about 600 ppm, with a high of about 800 ppm.

From the above measured data, it is shown that the average CO_2 levels in the building were more than 1,000 ppm in some units with 3 or more occupants and less than 1,000 ppm in units with two or less number of occupants. At the time of the monitoring, these levels of carbon dioxide levels may not be acceptable for maintaining the occupant comfort.

3.5. CARBON MONOXIDE

In this building, the carbon monoxide levels in the suites ranged from negligible values to a maximum value of about 2.8 ppm. The higher levels of carbon monoxide level, although significantly lower than the maximum allowable value of 11 ppm, was measured in unit 5 due to its exposure to street traffic.

3.6. ELECTROMAGNETIC FIELDS (EMFS)

The intensity of electromagnetic fields were measured in some suites. The electromagnetic fields were measured with and without power turned on in the living area. As shown in the following Table 4, the EMF readings were well below recommended levels of 8 milligauss in this building.

Figure 6: Profile of carbon dioxide levels in a test suite.

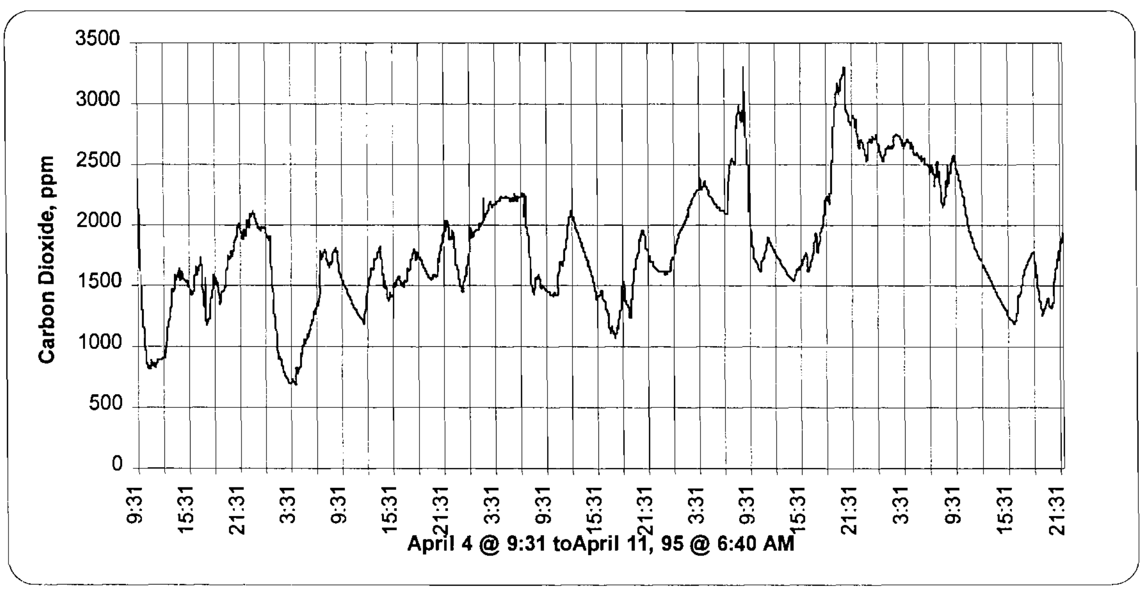
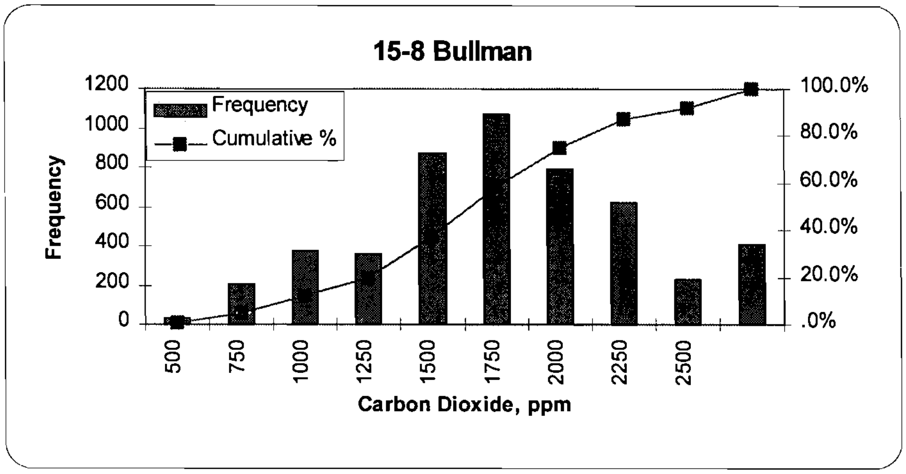


Table 4: Electromagnetic fields in suites with and without power on.

		Living Room (milligauss)		Master Bedroom (milligauss)		Kitchen (milligauss)		Bathroom (milligauss)	
Building	Unit	with	without	with	without	with	without	with	without
Ottawa 'B'	5	1.18				1.19			
	15	1.67	1.41						
	19	4.38	3.4			3.78	3.01		

Figure 7: Frequency distribution of carbon dioxide levels in a test suite.



3.7. VOLATILE ORGANIC COMPOUNDS (VOCS)

The VOCs were sampled in three apartment units for a period of one week. Table 5 shows the traces of some VOC compounds in the building. This unit was chosen because low air changes and the higher levels of CO_2. The measured levels of VOCs are significantly lower than the target level of 1 mg/m^3 for acceptable indoor air quality in residences.

Table 5: Volatile Organic Compounds in the test building.

	Unit	Target Compound	Result (mg/m^3)
Ottawa 'B'*	5	TVOC	0.86
	15	x-pinene d-limonene	0.16 0.47
	19	TVOC	0.45

3.8. FORMALDEHYDE

Two AQR dosimeters were placed in 2 apartment units for a period of seven days. The formaldehyde levels were about 0.06 ppm in one unit and 0.027 ppm in other unit. The formaldehyde levels were significantly lower than action limit of 0.10 ppm by Health Canada.

3.9. LIGHTING LEVELS

Lighting levels were measured in common area and corridors. Table 6 summarizes the average levels of lighting in the building. As shown, the stairwell lighting levels are affected by large openable windows.

Table 6: Lighting levels in the common area of building.

Common Area	Lighting Level (foot candles)
Corridors	12
Front Lobby	8
Elevators	none
Elevator Lobbies	none
Stairwells	32
Laundry Room	none
Recreation Room	none

4. ENERGY PERFORMANCE OF THE BUILDING

The energy performance of the building was evaluated using the DOE-2.1E energy simulation program. Data input files for the energy simulation programs were created using the field survey of various components, equipment and systems, and using the architectural drawings of the building.

4.1. UTILITY BILLS

This is an all electric building where individual tenant pays for the electricity. The common area bill is paid by the Co-operative which is proportionally charged to tenants through monthly rent. The project team formally requested all tenants to provide utility bills for at least a period of one to two years. The annual energy use totals were developed using the tenant bills. Using the utility bills collected from tenants and the common area bills, estimates were made for the total energy consumption. The analysis of utility bills showed that the annual energy consumption during 1993 was 266,083 kWh and during 1994 was 249,710 kWh.

4.2. ENERGY ANALYSIS RESULTS

A detailed energy analysis was undertaken to evaluate the energy performance of the building. DOE-21.E input data files were prepared and were simulated using the Ottawa weather files for the 1993 and 1994 years.

The hourly energy analysis showed that the annual heat losses during the heating season accounted for a total of 163.6 MWh. Heat loss components are shown in Figure 8. Conduction heat losses through walls accounted for 20 MWh (12.3%). Roof and below grade components accounted for 9.5 MWh (5.8%) and 9.2 (5.6%) MWh respectively. Heat losses through windows accounted for about 50 MWh (30.6%) annually. The mechanical ventilation in the building accounted for 11.2 MWh (6.8%). The air leakage heat losses were about 63.7 MWh (38.9%).

The heat gains in the building includes solar and internal gains. The internal gains are sensible heat gains due to occupancy, lighting, hot water and other energy consuming equipment. As shown in Figure 9, the total heat gains during the heating season were about 163.6 MWh. Solar gains accounted for 21.3 MWh (13%) of energy for offsetting the purchased energy requirements for the building. The internal gains were about 37.4 MWh or 22.9% of the total. The purchased space heating energy was about 104.9 MWh or 64.1% of the total energy requirements in the building.

The DOE-2.1E simulation for the weather year showed that the total energy requirement for 1994 is about 252.3 MWh. The energy use profile is shown in Figure 11. As shown in the figure, the lighting energy use is about 19.7% of the total. Space heating energy use accounted for 41.5% of the total energy use in the building. As shown in Table 7, the energy consumption profile compared well with the measured utility data. Figure 10 shows the energy cost balance sheet for the building. It can be seen from the balance sheet that energy use for space heating and domestic hot water accounts for more 2/3rd of the purchased energy costs. Energy conservation measures aimed at reducing the hot water use in the building and space heating controls can improve the energy efficiency. Due to lack of dedicated mechanical ventilation system in the building, air leakage control measures should not be considered.

Table 7: Summary of estimates and actual use of energy in the building.

Year	Electricity (kWh) Common Areas	Electricity (kWh) Apartments	Total Electricity (kWh)	Total Electricity DOE2.1e (kWh)
1993	38,940	227,143	266,083	261,724
1994	40,260	209,450	249,710	252,325

Figure 8: Heat loss components.

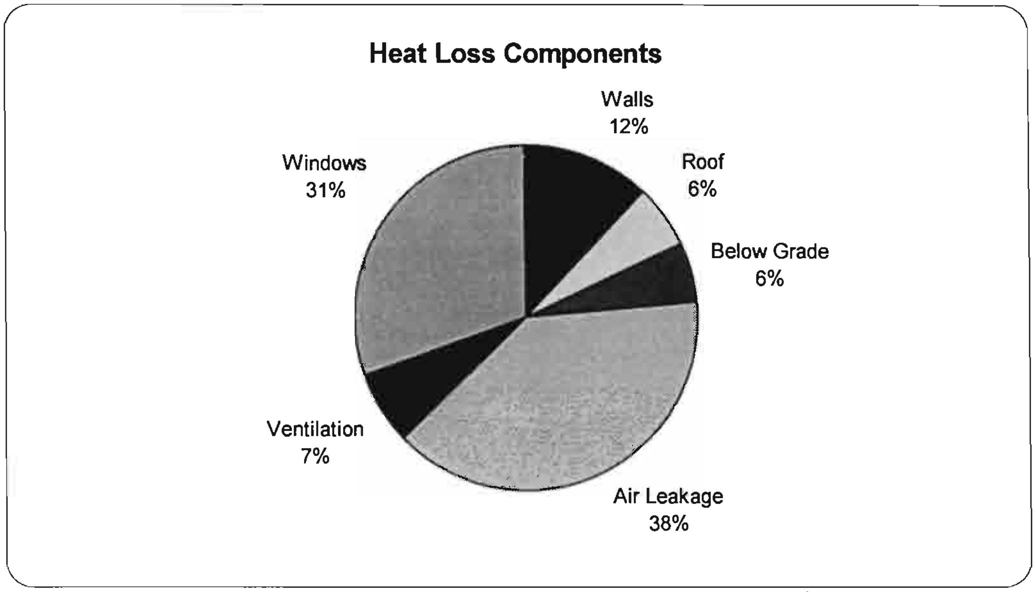


Figure 9: Components of heat gains in the building.

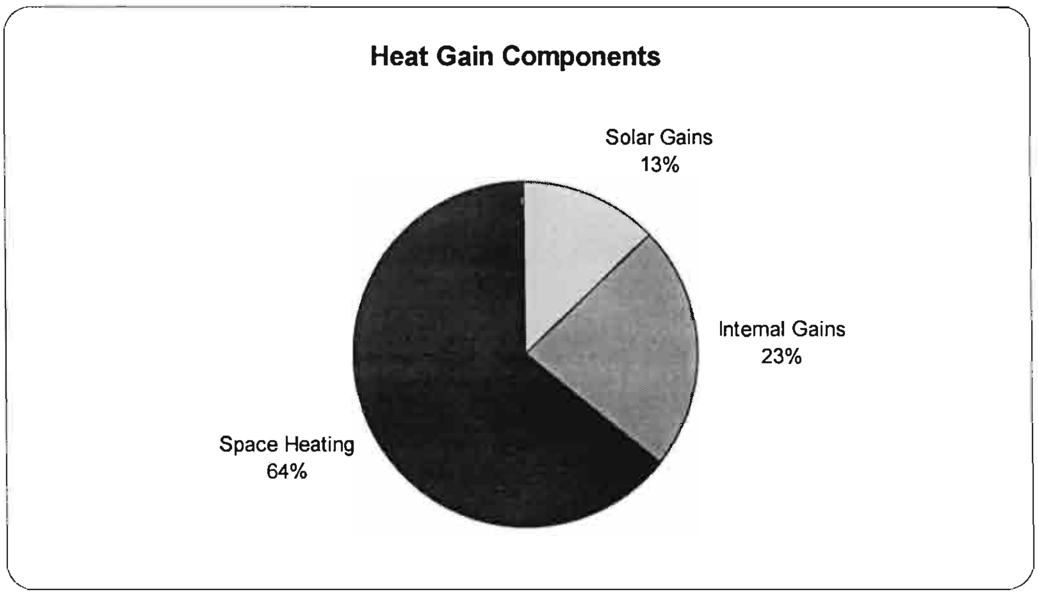
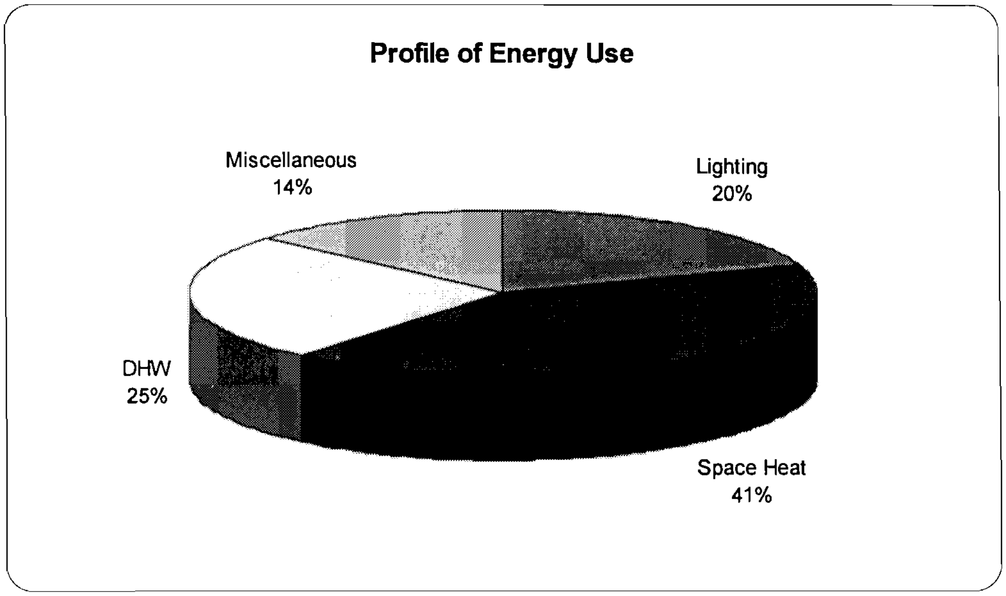


Figure 10: Energy cost balance sheet for the building (based on DOE-2.1E estimates).

Year 1994

Cost of Energy Supply			Cost of Energy Use		
Solar Gains	$ 1,638	6 8%	Walls, Roof and Below Grade	$ 2,975	12 4%
Internal Gains	$ 2,872	12 0%	Windows and Exterior Doors	$ 3,838	16.0%
Space Heating	$ 8,052	33 7%	Air Leakage	$ 4,888	20 4%
DHW	$ 4,869	20 4%	Ventilation	$ 860	3 6%
Base Use	$ 6,490	27 1%	DHW+Base Use	$ 11,359	47 5%
Estimated Energy Supply Cost	**$ 23,921**		**Estimated Cost of Energy Use**	**$ 23,921**	

Figure 11: Profile of energy use in the building.



5. DISCUSSION AND COMMENTS

The following comments pertain to the building performance and comparisons with appropriate required construction practices:

- The field survey showed that the building is well kept and well maintained. The airtightness test showed that the envelope air leakage is about 2.31 L/s.m^2 at 75 Pa pressure difference. The airtightness value is significantly higher than what can be expected in buildings with air barrier systems which ranges from as low as 0.05 to 0.3 L/s.m^2 at 75 Pa pressure difference. The window and wall joints, and balcony door frame and wall joints seem to be the cause of the poor airtightness. The visual observations of walls with optical fibroscope revealed proper levels of insulation and other details. This building generally satisfies the thermal characteristics of envelope components as per the 1990 Ontario Building Code.
- The inadequate indoor air-quality in the building may be due to the absence of dedicated make-up air mechanical ventilation system. The lack of proper ventilation in the building has been confirmed through the monitoring of high levels of carbon dioxide and the reporting of window condensation in most apartment units. Our review of the ventilation system showed that the building meets the intent of the 1990 OBC for providing required natural or mechanical ventilation requirements. However, the actual performance monitoring showed that the ventilation systems (natural and mechanical) did not perform as per the minimum requirements for human comfort as per the CSA F-328.
- The annual purchased energy in the building is about 150 kWh/m^2 (13.9 kWh/ft^2) of the floor space. About 41% of the total annual energy is attributed to the space heating requirements and 25% of annual energy use is for domestic hot water needs.
- To improve the occupant comfort, the building should be provided with a central make-up air system and the existing in-suite exhaust fans should be replaced.

Appendix A-2: Ottawa 'R' Building

Energy Analysis

ENERGY USE AND INDOOR AIR QUALITY IN MID-RISE APARTMENT BUILDINGS

Field Investigation and Energy Analysis Report

Appendix A-2: Ottawa 'R' Building

1. FIELD SURVEY

The subject building is a 4-storey apartment building with a partial basement and underground parking area. It is owned and operated by City Living, the City of Ottawa's Non-Profit Housing Corporation, and was built in 1991. It is an L-shaped building with East and West wings. The building is surrounded by low-rise residential buildings. At the time of the field survey, the building was fully occupied. As part of the project, a detailed field survey was undertaken and an inventory of energy consuming equipment and systems was prepared. The field survey included the data collection of building and systems information required for hourly energy simulation using the DOE-2.1E. The indoor environment survey was conducted using test protocols which are described in Appendix B.

The following briefly describes various building characteristics:

- **Building Layout:** This is a east-west axis building with a major portion of windows facing north and south. The main entrance is located in the north direction. The envelope construction is brick veneer steel studs.

  The gross floor area of the building is 2,937 m^2 There are 35 apartments consisting of the following types of suites:

  - 12 one-bedroom units with approximately 48.5 m^2 of floor area each (two layouts);
  - 14 two-bedroom units with approximately 60.5 m^2 of floor area each (two layouts);
  - 8 three-bedroom units with approximately 74.5 m^2 of floor area each (two layouts); and
  - 1 bachelor unit with approximately 34.5 m^2 of floor area.

  Common areas and their approximate sizes include a laundry room (13 m^2), a garbage room (13 m^2) and a common room (23 m^2) on the ground floor, and a service room on each of the top 3 floors (7 m^2 each). The total area of common spaces, not including corridors and lobbies, is approximately 70 m^2. There is underground parking for 28 cars.

  According to the building superintendent, all suites are occupied. Majority of occupancy is for seniors with few families.

- **Building Envelope:** This is a 4 storey brick veneer steel stud apartment building. The exterior walls consist of 90 mm face brick, 25 mm air space, building paper, 13 mm exterior grade gypsum board, 152 mm steel studs, 152 mm batt insulation, 6 mil poly vapour barrier and 13 mm gypsum wall board. The steel studs cover approximately 24% of the area. The effective thermal resistance of the wall assembly was estimated to be about RSI 2.14.[1]

[1] The effective thermal resistance of the envelope assembly was determined using the DOE-2.1E program's material and component library

The roof structure consists of 50 mm gravel bed, 5 mil poly protection sheathing, 100 mm rigid insulation, built-up roofing membrane and sloped concrete roof slab. The effective thermal resistance of the roof assembly was estimated to be about RSI 3.37.

There are several sizes of windows in the building. About 70% of windows are double-glazed picture windows with thermally broken aluminum framing. The other 30% are horizontal slider windows. The field survey showed that the weatherstripping on theses windows was in good acceptable condition. It was also reported by the superintendent that some tenants keep their windows slightly open even during winter months.

The basement level of the building is completely drywalled from inside. The below grade concrete walls are 200 mm thick and have been insulated using the interior placement of R-8 batts. The underground parking is not insulated.

Window condensation was reported during the cold winter months in most units. Several units had mold and mildew problems.

- **Space Heating System:** The suite space heating system consists of perimeter electric baseboards. Each electric baseboard is controlled by a line-voltage thermostat located in the centre of a room. Most baseboard heaters are located below windows.

  The forced-air make-up air system is provided for the corridor and common area ventilation. The make-up air is heated using the natural gas. The make-up air heater's output is rated at 234,000 Btu/hr (68.6 kW) which can be modulated to a minimum value of 99,000 Btu/hr (29 kW). There are two constant volume make-up air fans each one is rated at 2,200 CFM (1,051 L/s) with a 1.12 kW motor. The make-up air fan is scheduled to operate about 10 hours each day (08:00 to 13:00 and 16:00 to 21:00 hours). The heating capacity is controlled by a proportional controller based on supply air delivery temperature.

- **Domestic Hot Water System:** Each suite has an individual (unitary) electric hot water tank. The hot water tank capacity is about 60 US gallons or 227 L. The nameplate rating of each heater is about 4.2 kW. The hot water temperature is set at around 60 °C (140 °F).

- **Ventilation Systems and Strategies:** Each suite has a bathroom exhaust fan and a kitchen hood fan. These fans are operated manually.

  The make-air system provides ventilation to corridors and common area rooms. There are two fans and each fan is rated at 2,200 CFM (1,051 L/s) and is scheduled to operate for 10 hours each day. Corridor air can enter into suites through the door undercut.

- **Lighting System:** The corridor and common area lighting system includes conventional fluorescent lamps. In each suite, tenants use the conventional lamps and high intensity lighting fixtures. The exterior lighting system uses energy-efficient fixtures.

- **Appliances and Other Systems:** Laundry room is located in the basement which includes six sets of washer and dryer equipment. Each suite has four major appliances such as stoves, refrigerator, dishwasher and microwave. Most suites have one television set and a stereo system. It was found that some suites are loaded with electronic entertainment gadgets and even exercise equipment.

- **Metering:** Each suite is individually metered for the electricity use and bills are paid by tenants. The common area and central services, such as electricity, natural gas, water and sewer, are metered on bulk rates and bills are paid by the building owners.

2. AIR LEAKAGE AND VENTILATION SYSTEMS

2.1. AIR LEAKAGE TEST

The air leakage characteristics of the building envelope was determined using the whole building airtightness tests. The whole building airtightness tests were conducted using the test protocol developed by National Research Council for CMHC[2]. The airtightness test results were evaluated using the analytical procedures described in the CGSB Standard 149.10.[3]

For conducting the airtightness test, three blower doors were setup in the building. The airtightness characteristics were as follows:

Table 1: Air leakage characteristics of the test building.

C, L/(s.Pa^n)	178.149	L/(sPa^n)
n	0.736	
ACH at ΔP of 50 Pa	1.78	ac/hr
ELA at ΔP 10 Pa	3,897	cm^2
Airtightness	1.653	L/sm^2 at 50 Pa
	2.228	L/sm^2 at 75 Pa

2.2. AIR CHANGE RATE TEST

The air change rate was determined in three units using the passive sampling devices (PFT) for a period of one week. Table 2 shows the normal air change rate measured during the one week period. The air change rate includes effects of both the natural air change due to the air leakage and the mechanical ventilation in the building. It should be noted that the windows in all units were closed during the testing.

Table 2. Air change rate determined using the PFT sampling.

Building	Unit	Result (ACH)
Ottawa 'R'	106	1.06
	207	0.60
	404	0.47

2.3. CORRIDOR MAKE-UP AIR SYSTEM

The purpose of the measurements of the corridor make-up air flows were to determine the performance of make-up air ventilation system. Table 3 shows the air flow measurements. At the time of testing, make-up air fans delivered a total of 1,743 L/s. The design capacity of make-up air system is about 2,102 L/s.

Table 3: Measurements of corridor make-up air flows.

Building	Floor	Measured Air Flow (L/s)
Ottawa 'R'	1st	440
	2nd	223
	3rd	640
	4th	440

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[2] CMHC 1990 **Establishing the protocols for measuring air leakage and air flow patterns in high-rise apartment buildings.** Prepared by R J Magee and C Y Shaw of IRC/NRC for CMHC, Ottawa.

[3] CGSB 1988 **CGSB Standard 149.10 (new draft - 1994) — Determination of Airtightness of Building Envelopes by the Fan Depressurization Method**, Canadian General Standards Board, Ottawa, Ontario

The air supply to suites from the corridor through the apartment door was found to be as follows:

Table 4: Air supplied to suites from apartment door undercut.

Building	Unit	Measured Air Flow (L/s)
Ottawa 'R'	106	17
	207	18
	404	13

2.4. KITCHEN AND BATHROOM EXHAUST FANS

The air flow rates were measured for kitchen and bathroom exhaust fans in the test units. As shown in Table 5, the kitchen and bathroom fans significantly under performed. The fan ratings showed that the bathroom fan was designed to provide 25 L/s (50 CFM) and the kitchen fan to provide 80 L/s (160 CFM). The reason for the under performance of these fans was not investigated due to the scope and nature of the present study.

Table 5: Air flow measurements of kitchen and bathroom fans.

		Kitchen		Bathroom
Building	Unit	Flow (High) (L/s)	Flow (Low) L/s	Flow (L/s)
Ottawa 'R'	106	51	n/a	16
	207	67	n/a	12
	404	35	n/a	17.5

3. INDOOR ENVIRONMENT PARAMETERS

3.1. OCCUPANT SURVEY

A questionnaire was distributed to each tenant in the building. Questions were designed to determine the opinions of tenants with regard to the performance of the building and status of the indoor air quality. The sample questionnaire, both in English and French, is provided in Appendix B. Questions pertained to:

- the performance of the building in terms of indoor air quality, odour and moisture control;
- the use of the building including the presence of pets and smokers, and time spent at home; and
- general health including identification of asthma and allergies.

The survey questionnaire was distributed to all 35 apartments. Completed survey forms were returned by 19 tenants. The response rate was about 54%.

The number of tenants occupying each suite was between 1 and 5, with an average of 2.4. About 42% of the respondents complained about the temperature; it was either too hot or inconsistent. Fewer people complained about the general air quality, although there was a significant number of people (58%) who were unhappy with the relative humidity, both in the summer and the winter; generally in both the summer and the winter tenants found the air to be too humid. There were a great many tenants (84%) with condensation on the windows in the winter, and half of them reported mould in their apartment. Although there was a significant number of tenants who had disagreeable odours in their units (53%), there was no obvious correlation between the detection of odours and complaints of general indoor air quality. About 37% reported health problems that they attributed to the building; many of these people also reported disagreeable odours.

3.2. INDOOR AIR TEMPERATURE

Indoor air temperatures were measured in three suites for a period of one week beginning on March 25, 1995 to March 30, 1995 using a continuous data logger. Data was collected at a 10 minutes interval.

Figure 1 shows a typical profile of the indoor air temperature in an occupied unit. Figure 2 shows the histogram of the measured temperature readings in the building. As shown, more than 80% of the time, in this unit, the indoor air temperature remained below 21 °C.

Figure 1: Profile of indoor air temperature in a test suite.

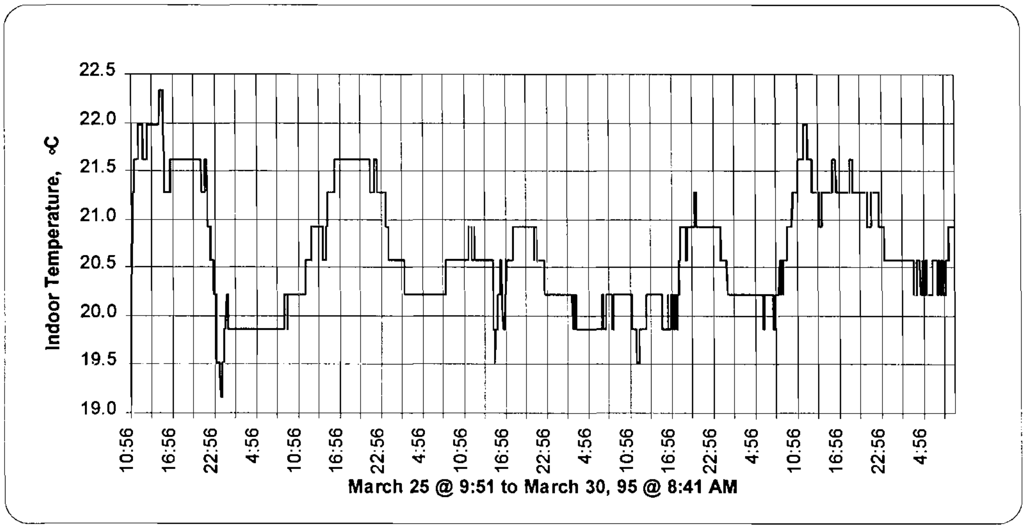
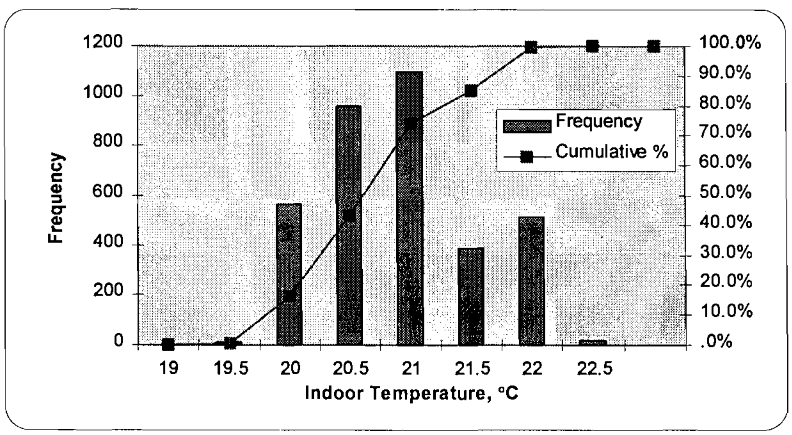


Figure 2: Frequency distribution of indoor air temperature in the test suite.



The measurements in three units can be summarized as follows:

- The highest recorded mean temperature was in the lowest apartment and the lowest mean temperature was in the middle apartment.
- Mean temperatures were between 20.6 and 24.0 °C.
- The maximum temperature recorded was 25.2 °C and the minimum was 19.2 °C, a difference of 6 °C. The differences in temperature between the recorded maximum and the recorded minimum in each apartment were 1.8, 3.1 and 2.4 °C. The apartment with the highest

maximum was also the apartment with the highest recorded minimum; likewise, the apartment with the lowest recorded maximum was also the apartment with the lowest recorded minimum.

- There does not appear to be a pattern with respect to daily cycling in apartment 106. Most temperatures were between 23.8 °C and 24.5 °C. In apartment 207, temperatures generally varied between 1.5 to 2 °C during any given day. Temperatures in 404 also varied by approximately 1.5 to 2 °C in a day, but generally stayed between 21 and 22 °C.

From the above measured data, it is shown that the average temperature in the building remained at around 21 °C. The outdoor conditions did affect the indoor temperatures. During the sunny days, the indoor temperature was about 3 °C higher than the nighttime values.

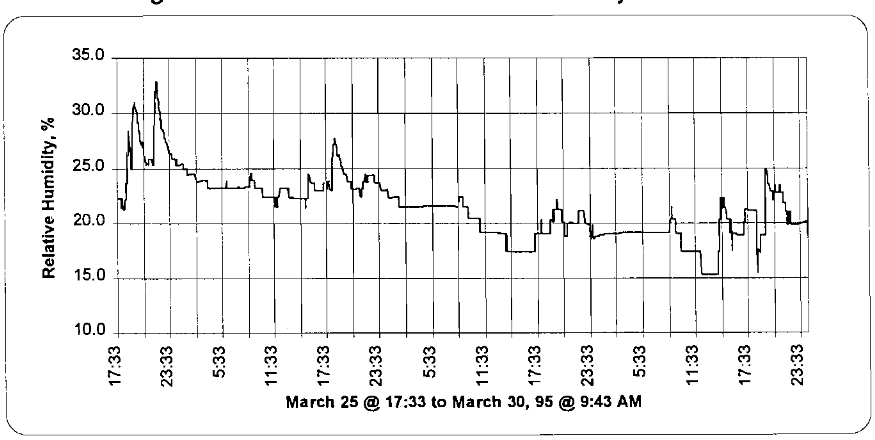
3.3. RELATIVE HUMIDITY

The relative humidity readings were taken in three suites for a period of one week beginning on March 25, 1995 to March 30, 1995 using a continuous data logger. Data was collected at 10 minutes intervals. Figure 3 shows a typical profile of the indoor relative humidity in an occupied unit. Figure 4 shows the histogram of the measured relative humidity readings in the building. As shown, more than 80% of the time, in this unit, the indoor relative humidity remained within a 25 to 30% range.

The measurements in three units can be summarized as follows:

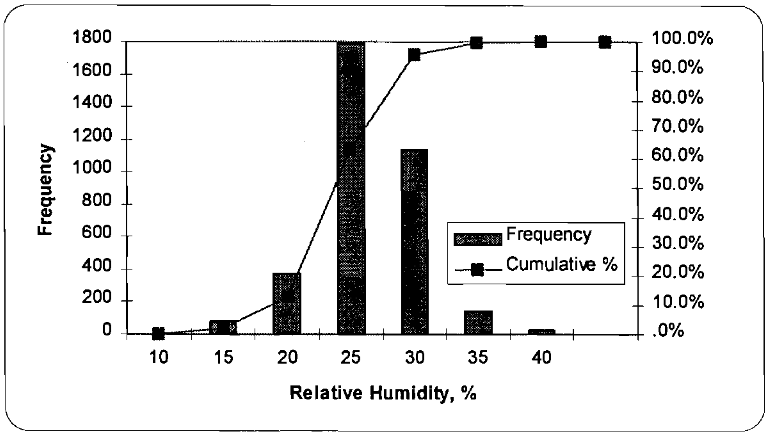
- The highest recorded mean RH was in the lowest apartment and the lowest mean RH was in the highest apartment.
- Mean RH was between 20.7 % and 30.1%.
- The maximum RH recorded was 41.9 % and the minimum was 11.5 %, a difference of 30.4%. The differences in RH between the recorded maximum and the recorded minimum in each apartment were 17.2, 28.6 and 17.9 %. The apartment with the highest maximum was also the apartment with the highest recorded minimum; however, the apartment with the lowest recorded maximum was not the apartment with the lowest recorded minimum.

Figure 3: Profile of indoor relative humidity in a test suite.



From the above measured data, it is shown that the average relative humidity in the building ranged from about 10% to 40% with an overall average of about 25%. At the time of the monitoring, this level of relative humidity is acceptable for maintaining the occupant comfort.

Figure 4: Frequency distribution of indoor relative humidity in the test suite.



3.4. CARBON DIOXIDE

The carbon dioxide readings were taken in three suites for a period of one week beginning on March 25, 1995 to March 30 11, 1995 using a continuous data logger. Data was collected at a 10 minute intervals. Figure 5 shows a typical profile of the carbon dioxide in an occupied unit. Figure 6 shows the histogram of the measured carbon dioxide readings in the building. As shown, more than 70% of the time, in this test unit, the carbon dioxide levels remained below 1,000 ppm. The average CO_2 levels were about 900 ppm slightly lower than recommended levels of about 1,000 ppm.

The daily range was generally around 900 ppm in apartment 106, with the majority of readings between 700 and 1400 ppm. The daily range was generally between 600 and 800 ppm in apartment 207, with the majority of readings between 800 and 1200 ppm. The daily range was generally about 450 ppm, with the majority of readings between 650 and 850 ppm in apartment 404.

From the above measured data, it is shown that the average CO_2 levels in the building were near to 1,000 ppm in some units with 3 or more occupants and less than 1,000 ppm in units with two or less number of occupants. At the time of the monitoring, these levels of carbon dioxide levels may seem to be high enough for maintaining the occupant comfort.

Figure 5: Profile of carbon dioxide levels in a test suite.

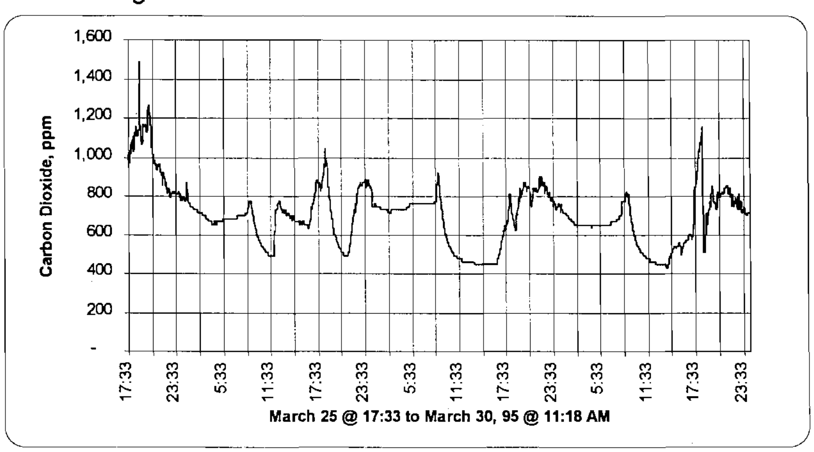
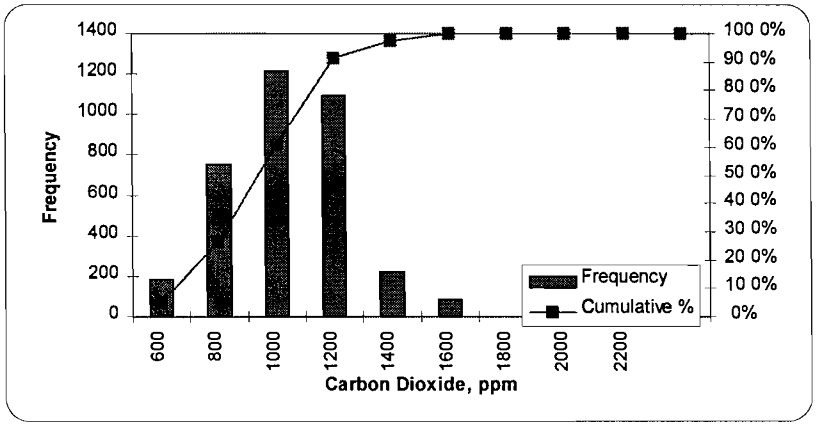


Figure 6: Frequency distribution of carbon dioxide levels in a test suite.



3.5. CARBON MONOXIDE

In this building, the carbon monoxide levels in the two suites ranged from negligible values to a maximum value of about 2 ppm. A sampler was also installed in the parking area which recorded a maximum level of about 8 ppm. The higher levels of carbon monoxide level is still significantly lower than the maximum allowable value of 11 ppm.

3.6. ELECTROMAGNETIC FIELDS (EMFS)

The intensity of electromagnetic fields were measured in some suites. The electromagnetic fields were measured with and without power turned on in the living area. As shown in the following Table 6, the EMF readings were well below recommended levels of 8 milligauss in this building.

Table 6: Electromagnetic fields in suites with and without power on.

		Living Room (milligauss)		Master Bedroom (milligauss)		Kitchen (milligauss)		Bathroom (milligauss)	
Building	Unit	with	without	with	without	with	without	with	without
Ottawa 'R'	106	1.52		1.6		1.62			
	207	1.92	1.08					3.00	2.27
	404	1.5	0.49						

3.7. VOLATILE ORGANIC COMPOUNDS (VOCS)

The VOCs were sampled in three apartment units for a period of one week. Table 7 shows the traces of some VOC compounds in the building. For detailed VOC analysis, unit (404) was chosen because low air changes and the higher levels of CO_2. The measured levels of VOCs are significantly lower than the target level of 1 mg/m^3 for acceptable indoor air quality in residences.

3.8. FORMALDEHYDE

Two AQR dosimeters were placed in 3 apartment units for a period of seven days. The formaldehyde levels were about 0.05, 0.03 and 0.04 ppm in Unit 106, 207 and 404 respectively. The formaldehyde levels were significantly lower than action level of 0.10 ppm suggested by Health Canada.

Table 7: Volatile Organic Compounds in the test building.

	Unit	Target Compound	Result (mg/m^3)
Ottawa 'R'	106	TVOC	0.28
	207	TVOC	0.06
	404	chloroform	0.002
		benzene	0.070
		toluene	0.27
		perchloroethylene	0.001
		ethyl benzene	0.024
		m-p xylenes	0.078
		oxylenes	0.030
		styrene	0.002
		dichlorobenzene	0.001
		d-limonine	0.38
		hexane	0.071
		1,2,4 trimethylbenzene	0.026

3.9. LIGHTING LEVELS

Lighting levels were measured in common area and corridors. Table 8 summarizes the average levels of lighting in the building. As shown, the stairwell lighting levels are affected by large openable windows.

Table 8: Lighting levels in the common area of building.

Common Area	Lighting Level (foot candles)
Corridors	10
Front Lobby	10
Elevators	30
Elevator Lobbies	10
Stairwells	40
Laundry Room	35
Recreation Room	20

4. ENERGY PERFORMANCE OF THE BUILDING

The energy performance of the building was evaluated using the DOE-2.1E energy simulation program. Data input files for the energy simulation programs were created using the field survey of various components, equipment and systems, and using the architectural drawings of the building.

4.1. UTILITY BILLS

The space heating in suite is accomplished using electric baseboards. The make-up air is heated with natural gas. The domestic hot water is provided by unitary electric hot water tanks. Individual unit tenant pays for the electricity bills. The common area bill, which includes common area electricity and natural gas use in the building, is paid by the Co-operative which is proportionally charged to tenants through monthly rent. The project team formally requested all tenants to provide utility bills for at least period of one to two years. The annual energy use totals were developed using the tenant bills. Using the utility bills collected from tenants and the common area bills, estimates were made for the total energy consumption.

4.2. ENERGY ANALYSIS RESULTS

A detailed energy analysis was undertaken to evaluate the energy performance of the building. DOE-21.E input data files were prepared and were simulated using the Ottawa weather files for the 1993 and 1994 years.

The hourly energy analysis showed that the annual heat losses during the heating season accounted for a total of 411.4 MWh. Heat loss components are shown in Figure 7. Conduction heat losses through walls accounted for 76.3 MWh (18.5%). Roof and below grade components accounted for 43.6 MWh (10.6%) and 32.1 (7.8%) MWh respectively. Heat losses through windows accounted for about 122.7 MWh (29.8%) annually. The mechanical ventilation in the building accounted for 62.1 MWh (15.1%). The air leakage heat losses were about 74.7 MWh (18.1%).

The heat gains in the building includes solar and internal gains. The internal gains are sensible heat gains due to occupancy, lighting, hot water and other energy consuming equipment. As shown in Figure 8, the total heat gains during the heating season were about 411.4 MWh. Solar gains accounted for 39.3 MWh (9.5%) of energy for offsetting the purchased energy requirements for the building. The internal gains were about 71.9 MWh or 17.5% of the total. The purchased space heating energy was about 300.3 MWh or 73% of the total energy requirements in the building.

The DOE-2.1E simulation for the weather year showed that the total energy requirement for 1994 is about 780 MWh. The energy use profile is shown in Figure 9. As shown in the figure, the lighting energy use is about 20.5% of the total. Space heating energy use accounted for 38.5% of the total energy use in the building. As shown in Table 9 and Table 10, the energy consumption profiles compared well with the measured utility data for two years of utility data.

Figure 7: Heat loss components.

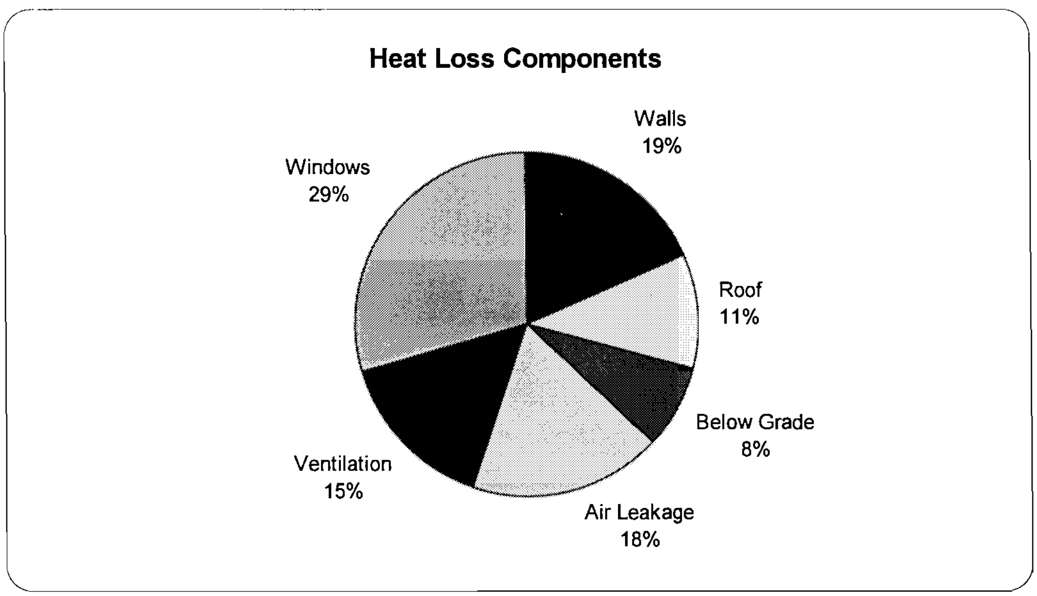


Table 9: Summary of estimates and actual use of electricity in the building.

Year	Electricity (kWh) Common Areas	Electricity (kWh) Apartments	Total Electricity (kWh)	Total Electricity DOE2.1e (kWh)
1993	236,520	357,408	593,928	588,280
1994	258,840	395,429	654,269	641,269

Figure 8: Components of heat gains in the building.

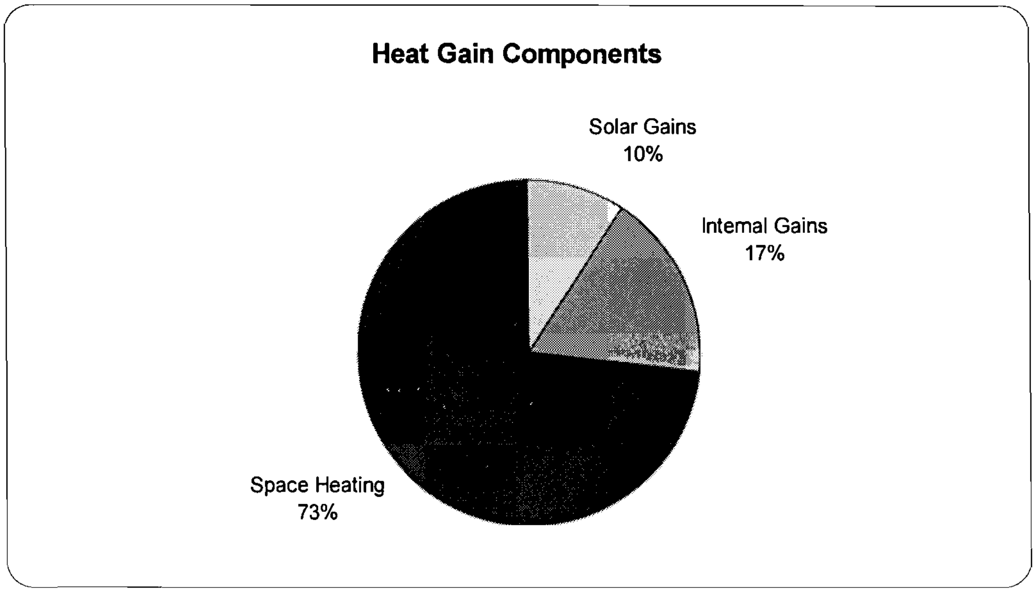


Table 10: Summary of estimates and actual use of natural gas in the building.

Year	Actual Gas Use(GJ)	Estimated Gas Use DOE21.e (GJ)
1993	481	470.5
1994	489	499.2

Figure 9: Profile of energy use in the building.

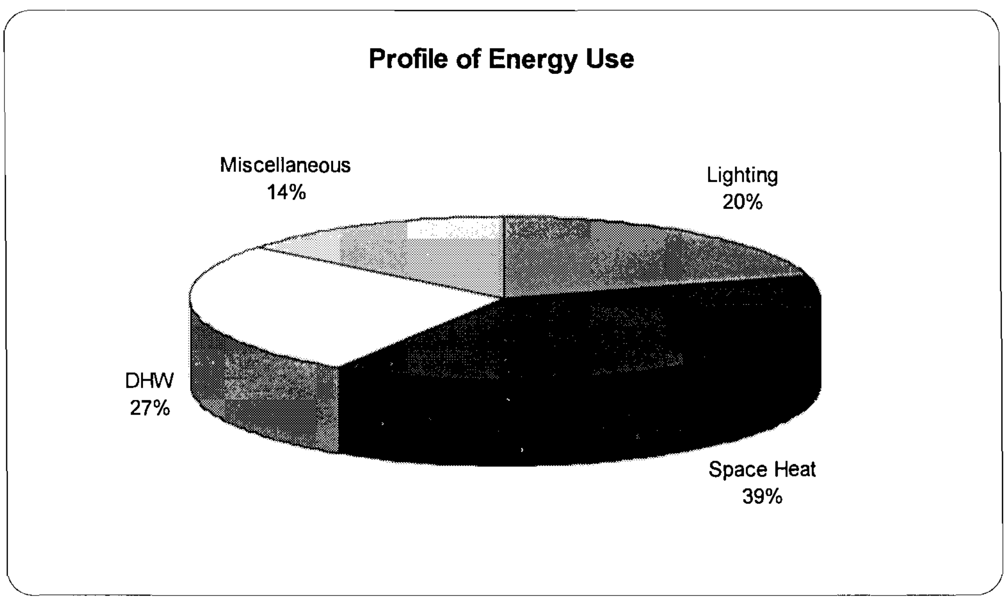


Figure 10 shows the energy cost balance sheet for the building. It can be seen from the balance sheet that energy use for space heating and domestic hot water accounts for more than 65% of the purchased energy costs. Energy conservation measures aimed at reducing the hot water use in the building and space heating controls can improve the energy efficiency. The electricity use for common area lighting and other appliances also constitutes major cost expenditures.

Figure 10: Energy cost balance sheet for the building (based on DOE-2.1E estimates).

Year 1994

Cost of Energy Supply			**Cost of Energy Use**		
Solar Gains	$ 2,137	3.7%	Walls, Roof and Below Grade	$ 8,265	14.2%
Internal Gains	$ 3,911	6.7%	Windows and Exterior Doors	$ 6,675	11.5%
Space Heating	$ 16,335	28.2%	Air Leakage	$ 4,061	7.0%
DHW	$ 15,426	26.6%	Ventilation	$ 3,381	5.8%
Base Use	$ 20,210	34.8%	DHW+Base Use	$ 35,636	61.4%
Estimated Energy Supply Cost	**$ 58,018**		**Estimated Cost of Energy Use**	**$ 58,018**	

5. DISCUSSION AND COMMENTS

The following comments pertain to the building performance and comparisons with appropriate required construction practices:

- The field survey showed that the building is well kept and well maintained. The airtightness test showed that the envelope air leakage is about 2.23 L/s.m^2 at 75 Pa pressure difference. The airtightness value is significantly higher than what can be expected in buildings with air barrier systems. The wall corners, roof/wall joint, window and wall joints, and balcony door frame and wall joints seem to be the cause of the poor airtightness. The visual observations of walls with an optical fibroscope revealed proper levels of insulation and other details. This building generally satisfies the thermal characteristics of envelope components as per the 1990 Ontario Building Code.
- The ventilation system provides adequate fresh air flows to corridors. However, significantly reduced quantity of fresh air is drawn from corridors to suites. The lack of proper levels of fresh air in the building led to higher levels of carbon dioxide and the reporting of window condensation in most apartment units. Our review of the ventilation system showed that the building meets the intent of the 1990 OBC for providing required natural or mechanical ventilation requirements. However, the actual performance monitoring showed that the ventilation systems (natural and mechanical) did not perform as per the minimum requirements as per the CSA F-326.
- The annual purchased energy in the building is about 263 kWh/m^2 (24.4 kWh/ft^2) of the floor space. About 38% of the total annual energy is attributed to the space heating requirements and 26% of annual energy use is for domestic hot water needs. The high space heating energy use is attributed to higher levels of thermal bridging in the building. The use of electrical appliances and lighting is also very high in the building.

Appendix A-3: Toronto 'L' Building

Building Report

ENERGY USE AND INDOOR AIR QUALITY IN MID-RISE APARTMENT BUILDINGS

Field Investigation and Energy Analysis Report

Appendix A-3: Toronto 'L' Building

1. FIELD SURVEY

The subject building is a 4-storey apartment building. The front of the ground floor is above grade; however, back and sides are on sloped grade which makes the half-height of the ground floor below grade. It is owned and operated by CityHome, a not for profit housing corporation in Toronto. It was built in 1991. It is a rectangular building. The building is surrounded by low-rise residential buildings. At the time of the field survey, the building was fully occupied. As part of the project, a detailed field survey was undertaken and an inventory of energy consuming equipment and systems was prepared. The field survey included the data collection of building and systems information required for hourly energy simulation using the DOE-2.1E. The indoor environment survey was conducted using test protocols which are described in Appendix B.

The following briefly describes various building characteristics:

- **Building Layout:** This is a east-west axis building with a major portion of windows facing north and south. The main entrance is located in the north direction. The envelope construction is brick veneer steel studs.

  The gross floor area of the building is 4,301 m^2. There are 51 apartments consisting of the following types of suites:

  - 12 one-bedroom units with approximately 50 m^2 of floor area (two layouts);
  - 17 two-bedroom units with approximately 66 m^2 of floor area (two layouts); and
  - 22 three-bedroom units with approximately 83 m^2 of floor area (five layouts).

  Common areas and their approximate sizes include a laundry room (22 m^2), sitting area (7 m^2), office (10 m^2), and garbage room (31 m^2) on the ground floor, garbage rooms on each of the top three floors (3 m^2 each), and a work room (115 m^2), a storage room (7 m^2), a communal storage room (33 m^2), a water meter room (21 m^2), and a building superintendent's storage room (25 m^2) in the basement. The total area of common spaces, not including corridors and lobbies, is approximately 279 m^2. There is an underground parking garage which is common to the seniors' building next door.

  According to the building superintendent, all suites are occupied. The majority of occupancy is for seniors with about 30% suites rented by families.

- **Building Envelope:** This is a 4 storey brick veneer steel stud apartment building. The exterior walls consist of 90 mm face brick, 25 mm air space, building paper, 13 mm exterior grade gypsum board, 152 mm steel studs, 152 mm batt insulation, 6 mil poly vapour barrier and 13 mm gypsum wall board. The steel studs cover approximately 22% of the area. The effective thermal resistance of the wall assembly was estimated to be about RSI 2.68.[1]

[1] The effective thermal resistance of the envelope assembly was determined using the DOE-2.1E program's material and component library.

The roof structure consists of 50 mm gravel bed, 5 mil poly protection sheathing, 100 mm rigid insulation, built-up roofing membrane and sloped concrete roof slab. The effective thermal resistance of the roof assembly was estimated to be about RSI 3.46.

There are several sizes of windows in the building. About 70% of windows are double-glazed picture windows with thermally broken aluminum framing. The other 30% are horizontal slider windows. The field survey showed that the weatherstripping of these windows was in good acceptable condition. It was also reported by the superintendent that some tenants keep their windows slightly open even during winter months.

The basement level of the building is completely drywalled. The below grade concrete walls are 200 mm thick and have been insulated using the interior placement of R-8 batts. The underground parking is not insulated.

Window condensation was reported during the cold winter months in more than 80% of units. Several units had mold and mildew problems.

- **Space Heating System:** The suite space heating system consists of a central hydronic system. Each hydronic radiator is controlled by a solenoid valve which is connected to a room thermostat located in the centre of a room. Most hydronic radiators are located below windows. There are two hot water boilers for the space heating. These boilers are rated at 183 kW and 153 kW. These boilers can be modulated to a minimum value of 52 kW each.

  The forced-air make-up air system is provided for the corridor and common area ventilation. The make-up air is heated using the natural gas-fired heater. There are two fresh air risers in the building, one with a capacity to provide 1,982 L/s of air and the other with a capacity to provide 1,322 L/s. The make-up air fans run continuously. There are two fans with rated capacity of 3.72 kW each. The heating capacity of gas heater is controlled by a supply air temperature controller.

- **Domestic Hot Water System:** There is a central domestic water system in the building. There are two domestic hot water boilers which use the natural gas. Each is rated at 175 kW. The hot water tank capacity is about 1,322 L. The hot water temperature is set at around 65 °C (149 °F).

- **Ventilation Systems and Strategies:** Each suite has a bathroom exhaust fan and a kitchen hood fan. These fans are operated manually.

  The make-air system provides ventilation to corridors and common area rooms. There are two fans with a rated capacity of 1,982 L/s and 1,322 L/s. These fans are scheduled to operate continuously. Corridor air can enter in to suites through the door undercut and door grilles.

- **Lighting System:** The corridor and common area lighting system includes conventional fluorescent lamps. In each suite, tenants use the conventional lamps and high intensity lighting fixtures. The exterior lighting system uses high-intensity conventional fixtures.

- **Appliances and Other Systems:** Laundry room is located in the basement which includes ten sets of washer and dryer equipment. Each suite has four major appliances such as stoves, refrigerator, dishwasher and microwave. Most suites have one television set and a stereo system.

- **Metering:** The building bulk metered for electricity, natural gas and water use.

2. AIR LEAKAGE AND VENTILATION SYSTEMS

2.1. AIR LEAKAGE TEST

The air leakage characteristics of the building envelope were determined using the whole building airtightness tests. The whole building airtightness tests were conducted using the test protocol developed by National Research Council for CMHC[2]. The airtightness test results were evaluated using the analytical procedures described in the CGSB Standard 149.10.[3]

For conducting the airtightness test, three blower doors were set up in the building. The airtightness characteristics were as follows:

Table 1: Air leakage characteristics of the test building.

C, L/(s.Pa^n)	280.869	L/(sPa^n)
n	0.834	
ACH at ΔP of 50 Pa	2.55	ac/hr
ELA at ΔP 10 Pa	7,703	cm^2
Airtightness	2.446	L/sm^2 at 50 Pa
	3.431	L/sm^2 at 75 Pa

2.2. AIR CHANGE RATE TEST

The air change rate was determined in three units using the passive sampling devices (PFT) for a period of one week. Table 2 shows the normal air change rate measured during the one week period. The air change rate includes effects of both the natural air change due to the air leakage, inter zone air movement and the mechanical ventilation in the building. It should be noted that the windows in all units were closed during the testing.

Table 2: Air change rate determined using the PFT sampling.

Building	Unit	Result (ACH)
Toronto 'L'	111	0.71 ± 0.11
	209	0.62 ± 0.08
	405	0.55 ± 0.1

2.3. CORRIDOR MAKE-UP AIR SYSTEM

The purpose of the measurements of the corridor make-up air flows was to determine the performance of make-up air ventilation system. Table 3 shows the air flow measurements. At the time of testing, make-up air fans delivered a total of 2,520 L/s. The design capacity of make-up air system is about 3,304 L/s.

Table 3: Measurements of corridor make-up air flows.

Building	Floor	Measured Air Flow (L/s)
Toronto 'L'	1st	606
	2nd	677
	3rd	521
	4th	716

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2 CMHC 1990. **Establishing the protocols for measuring air leakage and air flow patterns in high-rise apartment buildings.** Prepared by R J. Magee and C Y. Shaw of IRC/NRC for CMHC, Ottawa.

3 CGSB 1988. **CGSB Standard 149.10 (new draft - 1994) — Determination of Airtightness of Building Envelopes by the Fan Depressurization Method**, Canadian General Standards Board, Ottawa, Ontario

The air supply to suites from the corridor through the apartment door was found to be as follows:

Table 4: Air supplied to suites from apartment door undercut.

Building	Unit	Measured Air Flow (L/s)
Toronto 'L'	111	13
	209	20
	405	17

2.4. KITCHEN AND BATHROOM EXHAUST FANS

The air flow rates were measured for kitchen and bathroom exhaust fans in the test units. As shown in Table 5, the kitchen and bathroom fans significantly under performed. The fan ratings showed that the bathroom fan was designed to provide 25 L/s (50 CFM) and the kitchen fan to provide 40 L/s (80 CFM). The reason for the under performance of these fans was not investigated due to the scope and nature of the present study.

Table 5: Air flow measurements of kitchen and bathroom fans.

		Kitchen		Bathroom
Building	Unit	Flow (High) (L/s)	Flow (Low) L/s	Flow (L/s)
Toronto 'L'	111	24		16
	209	15		12
	405	27		20

3. INDOOR ENVIRONMENT PARAMETERS

3.1. OCCUPANT SURVEY

A questionnaire was distributed to each tenant in the building. Questions were designed to determine the opinions of tenants with regard to the performance of the building and status of the indoor air quality. The sample questionnaire, both in English and French, is provided in Appendix B. Questions pertained to:

- the performance of the building in terms of indoor air quality, odour and moisture control;
- the use of the building including the presence of pets and smokers, and time spent at home; and
- general health including identification of asthma and allergies.

The survey questionnaire was distributed to all 51 apartments. Completed survey forms were returned by 10 tenants. The response rate was about 20%.

The number of tenants occupying each suite was between 1 and 4, with an average of 2.1. The majority of tenants do not appear to be pleased with the indoor air quality. The majority of problems seem to be attributable to humidity levels. Although 50% found the air too dry in the winter, 80% of them had condensation on the windows in the winter. General disapproval of air quality was expressed by 50%; there is a correlation between those expressing dissatisfaction with the air (stale, stuffy or drafty), and those complaining of health problems that they attributed to the building. There does not appear to be any correlation between the presence of smokers or pets and complaints regarding indoor air quality.

3.2. INDOOR AIR TEMPERATURE

Indoor air temperatures were measured in three suites for a period of one week beginning on December 6, 1995 to December 13, 1995 using a continuous data logger. Data was collected at a 10 minutes interval.

Figure 1 shows a typical profile of the indoor air temperature in an occupied unit. Figure 2 shows the histogram of the measured temperature readings in the building. As shown, more than 80% of the time, in this unit, the indoor air temperature remained below 22.8 °C.

Figure 1: Profile of indoor air temperature in a test suite.

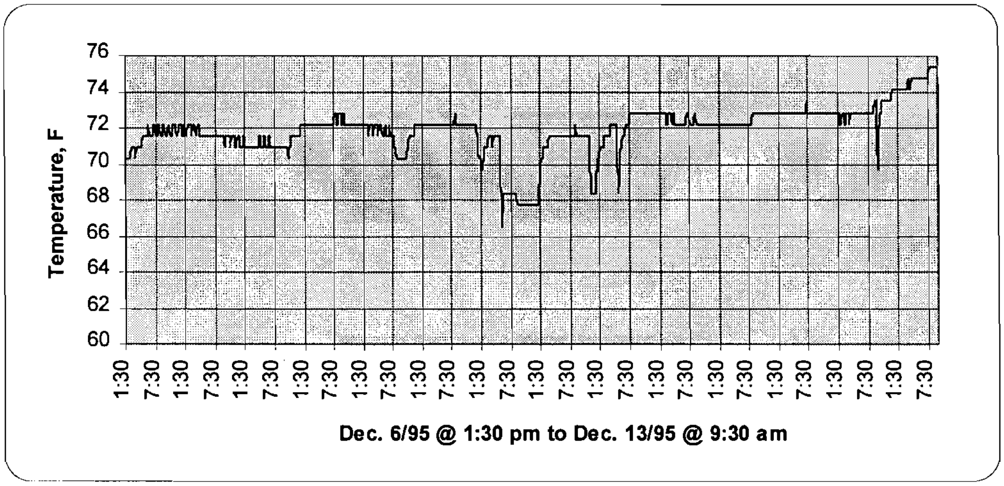
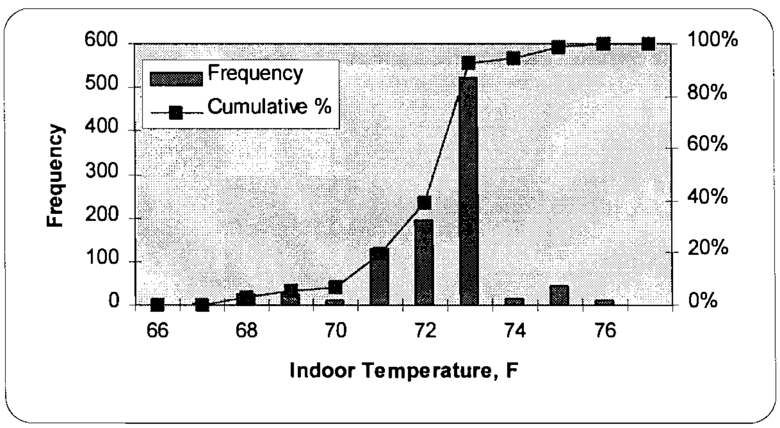


Figure 2: Frequency distribution of indoor air temperature in the test suite.



The measurements in three units can be summarized as follows:

- The highest mean temperature was in the lower apartment and the lowest mean temperature was in the higher apartment.
- Mean temperatures ranged between 22.1 and 23.8 °C.
- The maximum temperature recorded was 25.5 °C and the minimum temperature recorded was 19.1 °C, a difference of 6.4 °C. The differences in temperature between the recorded maximum and the recorded minimum in each apartment were 5 and 3.2 °C. The apartment with the highest maximum was also the apartment with the highest recorded minimum.

- Temperatures in apartment 209 were typically between 23.1 and 25.6 °C, with most of them between 23.3 and 24.4 °C. Temperatures were fairly constant, approximately 22.2 °C, in apartment 111; they fluctuated by as much as 2.8 °C in a day, but typically not more than 1.1°C.

From the above measured data, it is shown that the average temperature in the building remained at around 22 °C. The outdoor conditions did affect the indoor temperatures. During the sunny days, the indoor temperature was about 4 °C higher than the nighttime values.

3.3. RELATIVE HUMIDITY

The relative humidity readings were taken in three suites for a period of one week beginning on December 6, 1995 to December 13, 1995 using a continuous data logger. Data was collected at a 10 minutes interval. Figure 3 shows a typical profile of the indoor relative humidity in an occupied unit. Figure 4 shows the histogram of the measured relative humidity readings in the building. As shown, more than 80% of the time, in this unit, the indoor relative humidity remained within 20 to 30% range.

The measurements in three units can be summarized as follows:

- The highest mean RH was in the lower apartment and the lowest mean RH was in the higher apartment.
- Mean RH varied between 7.8% and 19.5 %.
- The maximum RH recorded was 29.1 % and the minimum was 5.5 %, a difference of 23.6 %. The differences in RH between the recorded maximum and the recorded minimum in each apartment were 14.6 and 13.1 %. The apartment with the highest recorded maximum was also the apartment with the highest recorded minimum.
- Relative humidity was fairly constant at approximately 6 % for much of the week in apartment 209; the first half of the week they fluctuated more, between 6 and 14 %. RH was mostly between 15 and 25 %, or more precisely, between 17 and 24 %, in apartment 111. Daily temperature swings were in the neighbourhood of 7 to 7.5 %.

From the above measured data, it is shown that the average relative humidity in the building ranged from about 15% to 28% with an overall average of about 20%. At the time of the monitoring, this level of relative humidity is minimum acceptable for maintaining the occupant comfort.

Figure 3: Profile of indoor relative humidity in a test suite.

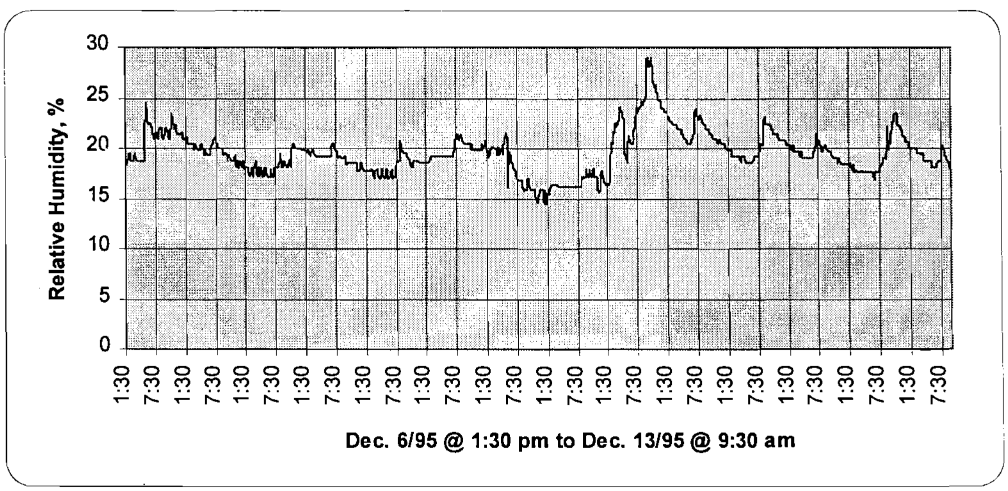
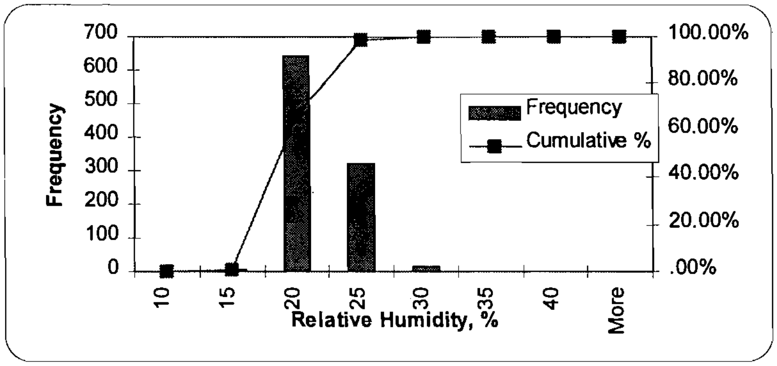


Figure 4: Frequency distribution of indoor relative humidity in the test suite.



3.4. CARBON DIOXIDE

The carbon dioxide readings were taken in three suites for a period of one week beginning on December 6, 1995 to December 13, 1995 using a continuous data logger. Data was collected at a 10 minutes interval. Figure 5 shows a typical profile of the carbon dioxide in an occupied unit. Figure 6 shows the histogram of the measured carbon dioxide readings in the building. As shown, almost all time, in this test unit, the carbon dioxide levels remained below 1,000 ppm. The average CO_2 levels were about 500 ppm which is much lower than recommended levels of about 1,000 ppm.

CO_2 fluctuates, typically, by about 400 or 500 ppm in a day, but in apartment 111, was found to be as high as 650 ppm in apartment 111. The majority of readings were between 600 and 800 ppm in apartment 111, and between 400 and 550 ppm in apartment 405. In apartment 209, CO_2 fluctuated between about 425 and 900 ppm, with very few readings in between.

From the above measured data, it is shown that the average CO_2 levels in the building were lower than 1,000 ppm in all units with 3 or more occupants and less than 800 ppm in units with two or less number of occupants. At the time of the monitoring, these levels of carbon dioxide levels were acceptable for maintaining the occupant comfort.

Figure 5: Profile of carbon dioxide levels in a test suite.

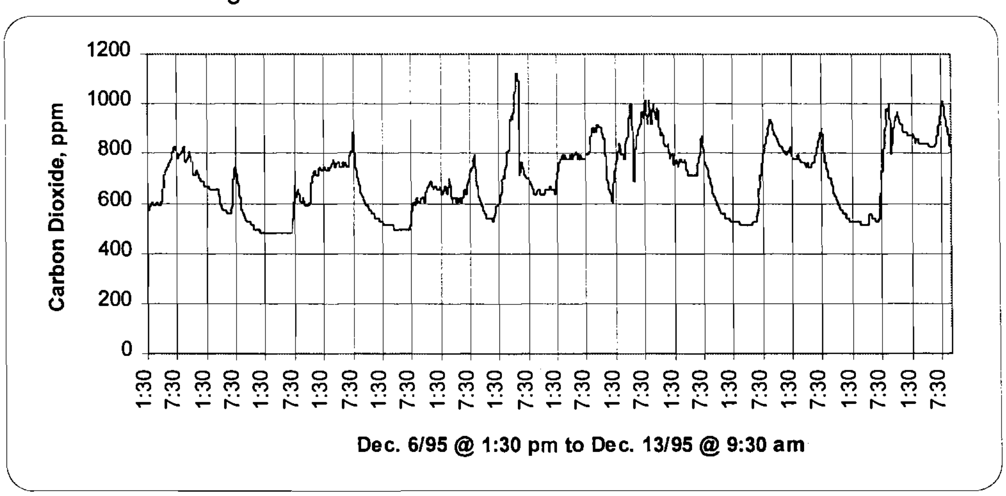
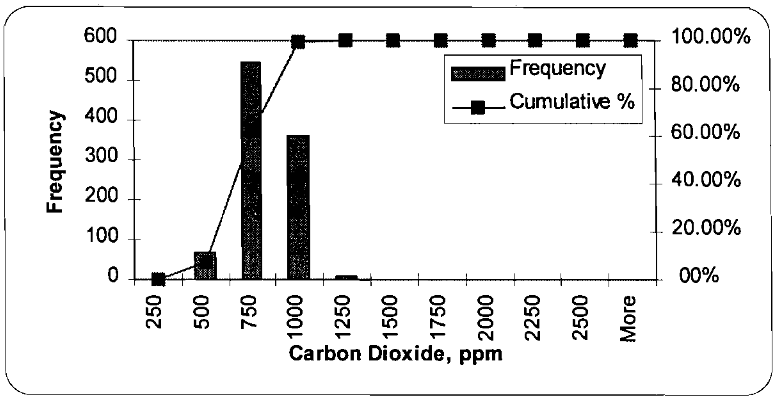


Figure 6: Frequency distribution of carbon dioxide levels in a test suite.



3.5. CARBON MONOXIDE

In this building, the carbon monoxide levels in the two suites ranged from negligible values to a maximum value of about 3 ppm. The higher levels of carbon monoxide level is still significantly lower than the maximum allowable value of 11 ppm.

3.6. ELECTROMAGNETIC FIELDS (EMFS)

The intensity of electromagnetic fields were measured in some suites. The electromagnetic fields were measured with and without power turned on in the living area. As shown in the following Table 6, the EMF readings were well below recommended levels of 8 milligauss in this building except in unit 111 bathroom. No immediate diagnosis can be arrived at figuring out the high EMF readings.

Table 6: Electromagnetic fields in suites with and without power on.

		Living Room (milligauss)		Master Bedroom (milligauss)		Kitchen (milligauss)		Bathroom (milligauss)	
Building	Unit	with	without	with	without	with	without	with	without
Toronto 'L'	111	1 64		1.27		4 31		8.45	
	209	1 01		0 90		1 12		1 02	
	405	0 74		0 47		1.34		0 34	

3.7. VOLATILE ORGANIC COMPOUNDS (VOCS)

The VOCs were sampled in three apartment units for a period of one week. Table 7 shows the traces of some VOC compounds in the building. For detailed VOC analysis, unit 111 was chosen because low air changes and the higher levels of CO_2. The measured levels of VOCs are significantly lower than the target level of 1 mg/m^3 for acceptable indoor air quality in residences.

3.8. FORMALDEHYDE

Two AQR dosimeters were placed in 3 apartment units for a period of seven days. The formaldehyde levels were about 0.01, 0.05 and 0.03 ppm in Unit 111, 209 and 405 respectively. The formaldehyde levels were significantly lower than action level of 0.10 ppm suggested by Health Canada.

Table 7: Volatile Organic Compounds in the test building.

	Unit	Target Compound	Result (mg/m^3)
Toronto 'L'	111	benzene	0.006
		toluene	0.015
		ethylbenzene	0.001
		m-p xylenes	0.004
		o-xylenes	0.001
		dichlorobenzene	0.013
		d-limonene	0.054
	209	TVOC	0.19
	405	TVOC	0.12

3.9. LIGHTING LEVELS

Lighting levels were measured in common area and corridors. Table 8 summarizes the average levels of lighting in the building. As shown, the stairwell lighting levels are affected by large openable windows.

Table 8: Lighting levels in the common area of building.

Common Area	Lighting Level (foot candles)
Corridors	11-90
Front Lobby	
Elevators	20
Elevator Lobbies	7-80
Stairwells	
Laundry Room	
Recreation Room	

4. ENERGY PERFORMANCE OF THE BUILDING

The energy performance of the building was evaluated using the DOE-2.1E energy simulation program. Data input files for the energy simulation programs were created using the field survey of various components, equipment and systems, and using the architectural drawings of the building.

4.1. UTILITY BILLS

The space heating in suite is accomplished using a central hydronic heating system. The make-up air is heated with natural gas. The domestic hot water is provided by a central hydronic boiler. The building is bulk metered for electricity, natural gas and water consumption. The annual energy use totals were developed using the electricity and natural gas bills. Utility bills were available for the full year of 1993 and part year of 1994. Energy analysis was therefore performed for the year 1993.

4.2. ENERGY ANALYSIS RESULTS

A detailed energy analysis was undertaken to evaluate the energy performance of the building. DOE-21.E input data files were prepared and were simulated using the Toronto weather files for the 1993.

The hourly energy analysis showed that the annual heat losses during the heating season accounted for a total of 551.2 MWh. Heat loss components are shown in Figure 7. Conduction heat losses through walls accounted for 29.6 MWh (5.4%). Roof and below grade components accounted for

19.3 MWh (3.5%) and 95.6 (17.3%) MWh respectively. Heat losses through windows accounted for about 210.2 MWh (38.1%) annually. The mechanical ventilation in the building accounted for 92.2 MWh (16.7%). The air leakage heat losses were about 104.4 MWh (18.9%).

The heat gains in the building includes solar and internal gains. The internal gains are sensible heat gains due to occupancy, lighting, hot water and other energy consuming equipment. As shown in Figure 8, the total heat gains during the heating season were about 551.2 MWh. Solar gains accounted for 64.9 MWh (11.8%) of energy for offsetting the purchased energy requirements for the building. The internal gains were about 92 MWh or 16.7% of the total. The purchased space heating energy was about 394.3 MWh or 71.5% of the total energy requirements in the building.

The DOE-2.1E simulation for the weather year showed that the total energy requirement for 1994 is about 758 MWh. The energy use profile is shown in Figure 9. As shown in the figure, the lighting energy use is about 9.7% of the total. Space heating energy use accounted for 53.8% of the total energy use in the building. As shown in Table 9 and Table 10, the energy consumption profiles compared well with the measured utility data for two years of utility data.

Figure 7: Heat loss components.

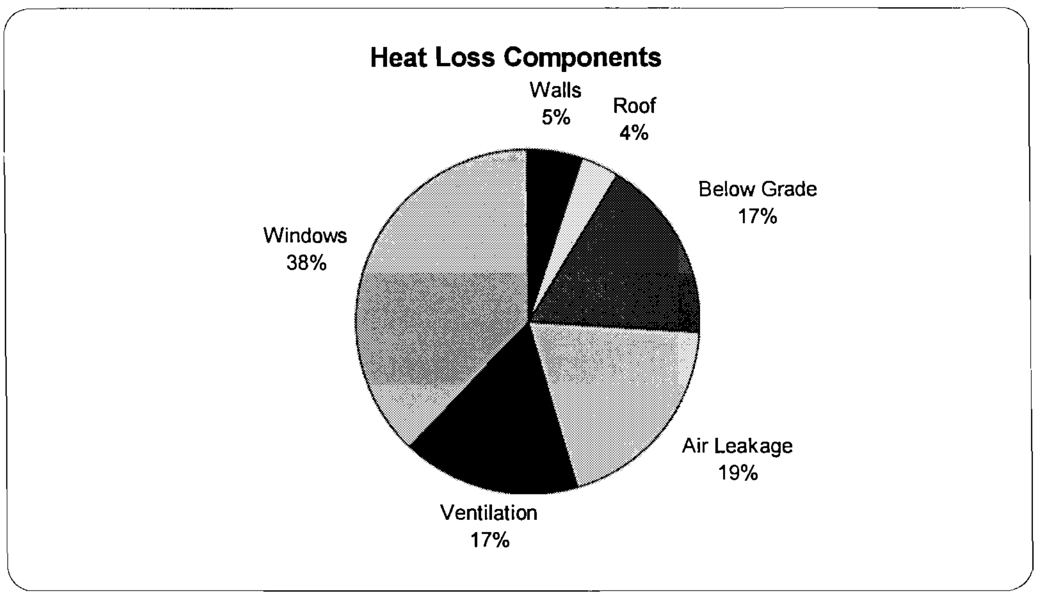


Table 9: Summary of estimates and actual use of electricity in the building.

Year	Electricity (kWh) Common Areas	Electricity (kWh) Apartments	Total Electricity (kWh)	Total Electricity DOE2.1e (kWh)
1993			348,303	338,159

Table 10: Summary of estimates and actual use of natural gas in the building.

Year	Actual Gas Use(GJ)	Estimated Gas Use DOE21.e (GJ)
1993	1,988.4	2,075.7

Figure 8: Components of heat gains in the building.

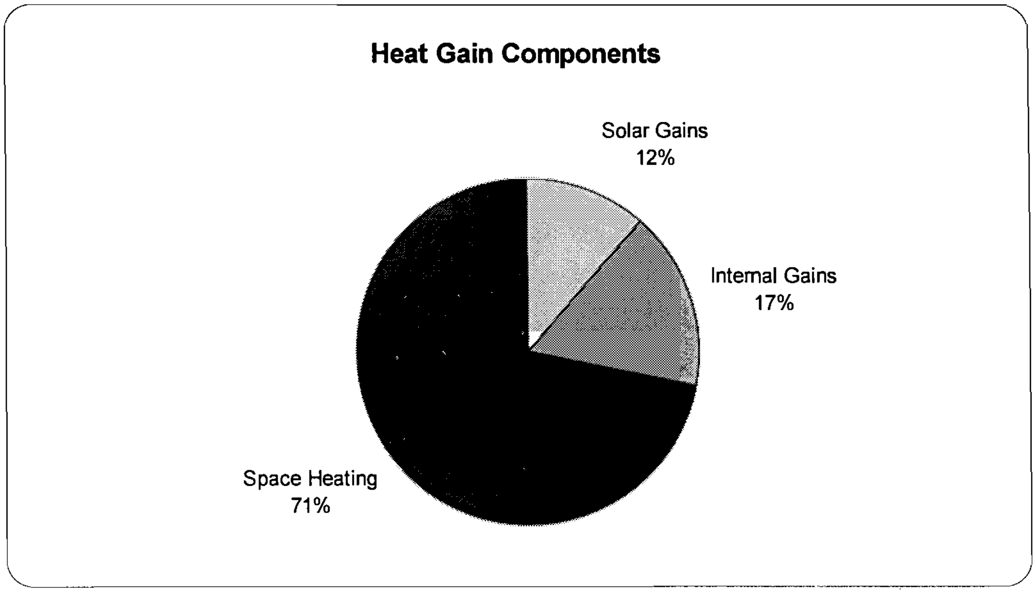


Figure 9: Profile of energy use in the building.

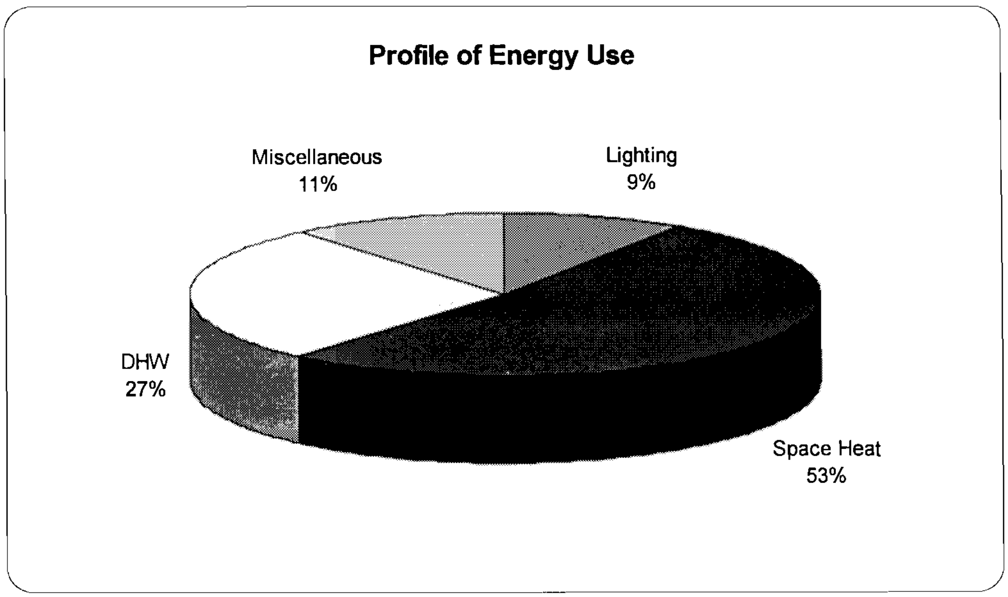


Figure 10: Energy cost balance sheet for the building (based on DOE-2.1E estimates).

Year 1993

Cost of Energy Supply			Cost of Energy Use		
Solar Gains	$ 2,460	6.1%	Walls, Roof and Below Grade	$ 5,478	13.6%
Internal Gains	$ 3,490	8 6%	Windows and Exterior Doors	$ 7,970	19 7%
Space Heating	$ 14,951	37 0%	Air Leakage	$ 3,959	9 8%
DHW	$ 7,876	19 5%	Ventilation	$ 3,494	8 7%
Base Use	$ 11,597	28 7%	DHW+Base Use	$ 19,472	48 2%
Estimated Energy Supply Cost	**$ 40,373**		**Estimated Cost of Energy Use**	**$ 40,373**	

Figure 10 shows the energy cost balance sheet for the building. It can be seen from the balance sheet that energy use for space heating and domestic hot water accounts for more than 65% of the purchased energy costs. Energy conservation measures aimed at reducing the hot water use in the building and space heating controls can improve the energy efficiency. The electricity use for common area lighting and other appliances also constitute major cost expenditure.

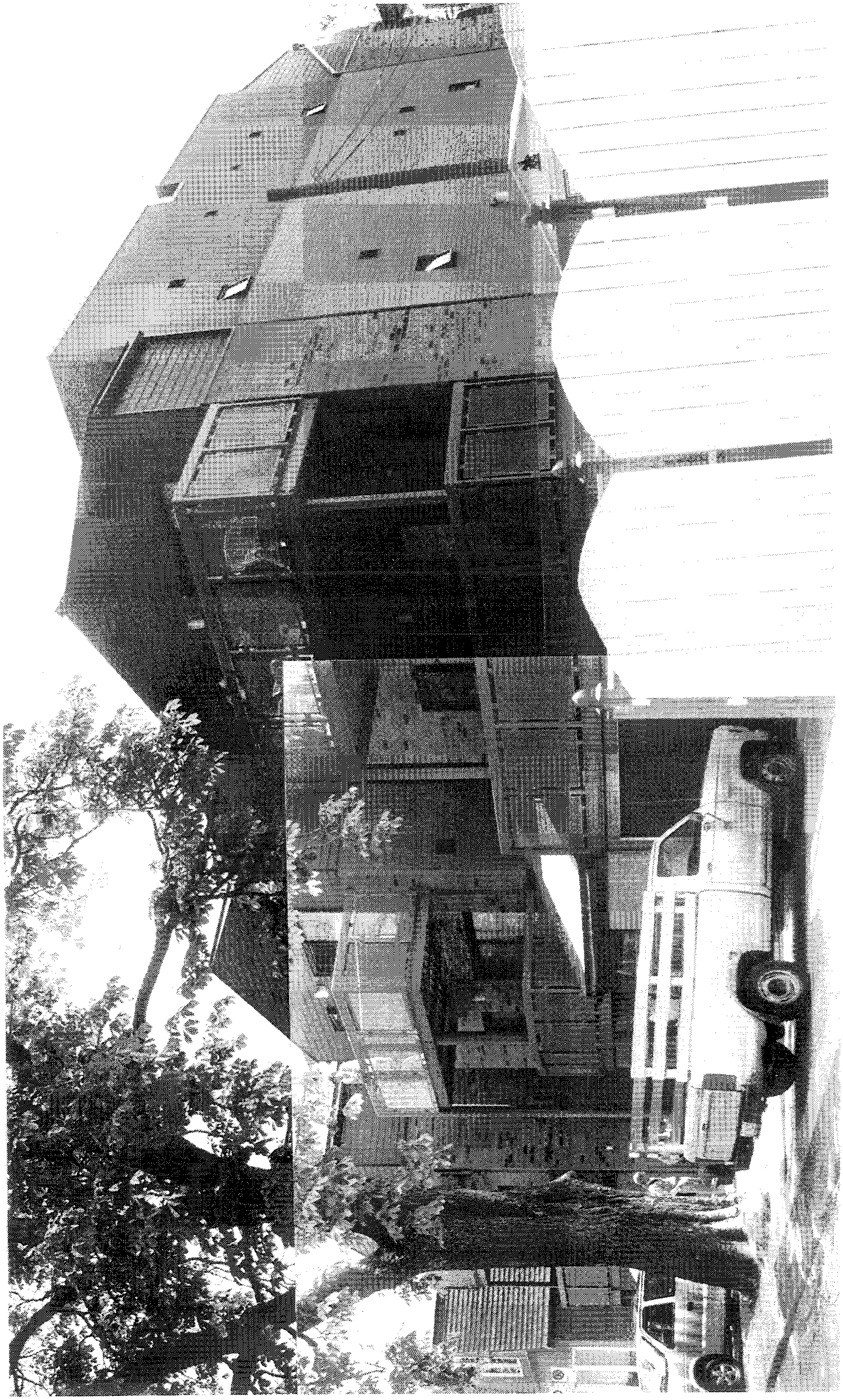
5. DISCUSSION AND COMMENTS

The following comments pertain to the building performance and comparisons with appropriate required construction practices:

- The field survey showed that the building is well kept and well maintained. The airtightness test showed that the envelope air leakage is about 3.43 L/s.m^2 at 75 Pa pressure difference. The airtightness value is significantly higher than what can be expected in buildings with air barrier systems. The visual observations of walls with optical fibroscope revealed proper levels of insulation and other details. This building generally satisfies the thermal characteristics of envelope components as per the 1990 Ontario Building Code.
- The ventilation system provides adequate fresh air flows to corridors. The corridor air leading to suites ranged from 13 to 20 L/s. The entry of make-up ventilation air in suites have kept the CO2 levels and formaldehyde levels significantly low. It seems that there is just sufficient amount of ventilation air is introduced in the suites. It also interesting to see that majority of occupants have reported that they feel air too dry in the winter months and also reported that there is condensation on windows. These contradictory observation lead us to believe that condensation on windows is occurring on a very small percentage of windows. Our review of the ventilation system showed that the building meets the intent of the 1990 OBC for providing required natural or mechanical ventilation requirements. The actual performance monitoring showed that the ventilation systems (natural and mechanical) did perform as per the minimum requirements as per the CSA F-326.
- The annual purchased energy in the building is about 170.3 kWh/m^2 (15.8 kWh/ft^2) of the floor space. About 54% of the total annual energy is attributed to the space heating requirements and 28% of annual energy use is for domestic hot water needs. The high space heating energy use is attributed to higher levels of thermal bridging in the building.

Appendix A-4: Toronto 'S' Building

Building Report



ENERGY USE AND INDOOR AIR QUALITY IN MID-RISE APARTMENT BUILDINGS

Field Investigation and Energy Analysis Report

Appendix A-4: Toronto 'S' Building

1. FIELD SURVEY

The subject building is a 3-storey apartment building located in Toronto. The building construction was completed in middle of 1994 and occupancy started just after that and by January 1995 building was fully occupied. It is a rectangular building. The building is surrounded by low-rise residential buildings. At the time of the field survey, the building was fully occupied. As part of the project, a detailed field survey was undertaken and an inventory of energy consuming equipment and systems was prepared. The field survey included the data collection of building and systems information required for hourly energy simulation using the DOE-2.1E. The indoor environment survey was conducted using test protocols which are described in Appendix B.

The following briefly describes various building characteristics:

- **Building Layout:** This is a NW-SE axis building with a major portion of windows facing north-east and south-west. The main entrance is located on the north.

  There are 17 apartment units, and underground parking for 2 cars. The gross floor area is 871.25 m^2. This building has the following types of suites:

  - 6 one-bedroom units with approximately 48 m^2 of floor area (one layout); and
  - 11 bachelor units with approximately 32 to 34 m^2 of floor area (three layouts).

  Common areas and their approximate sizes include a laundry room (15 m^2), a recreation room (34 m^2), a garbage room (15 m^2) and an electrical/mechanical room (21 m^2) on the ground on the floor, and a garbage room on each of the top two floors (4 m^2 each). The total area of common spaces, not including corridors and lobbies, is approximately 124 m^2.

  According to the building superintendent, all suites are occupied. The majority of occupancy is for seniors. Indoor air quality tests were conducted in three apartments: 103, 205 and 306.

- **Building Envelope:** This is a 3 storey wood frame apartment building. The exterior walls consist of 90 mm face brick, 32 mm air space, 50 mm glasclad, 13 mm exterior grade gypsum board, 2x4 wood studs @ 300 o.c., R-12 fiberglass batt insulation, 6 mil poly vapour barrier and 13 mm gypsum wall board. The wood studs cover approximately 26% of the area. The effective thermal resistance of the wall assembly was estimated to be about RSI 2.52.[1]

  The attic low slope roof consists of R-32 insulation. The effective thermal resistance of the roof assembly was estimated to be about RSI 3.25.

  There are several sizes of windows in the building. About 50% of windows are double-glazed picture windows with thermally broken aluminum framing. The other 50% are single hung windows. The field survey showed that the condition of the weatherstripping on these

[1] The effective thermal resistance of the envelope assembly was determined using the DOE-2 1E program's material and component library

windows was in good acceptable condition. It was also reported by the superintendent that some tenants keep their windows open even during winter months.

The basement level of the building is unfinished. The below grade concrete walls are 200 mm thick and have been insulated using the interior placement of R-8 batts. The underground parking is not insulated.

- **Space Heating System:** The suite space heating system consists of central hydronic system. Each hydronic radiator is controlled by a solenoid valve which is connected to a room thermostat located in the centre of a room. Most hydronic radiators are located below windows. There is one hot water boiler for the space heating which is rated at 330 MBtu (96.7 kW) which can be modulated to a minimum value of 66 MBtu (19 kW).

  The forced-air make-up air system is provided for the corridor and common area ventilation. The make-up air is heated by natural gas. There is one fresh air riser in the building with a capacity to provide 2500 CFM (1,180 L/s) of air. The make-up air fan runs continuously. There is one fan with a rated capacity of 2,500 CFM and a 0.75 HP motor. The heating capacity of gas heater is controlled by supply air temperature controller.

- **Domestic Hot Water System:** There is a central domestic water system in the building. There is one domestic hot water boiler which uses the natural gas and is rated at 251 MBtu (73.5 kW). The hot water tank capacity is about 318 L. The hot water temperature is set at around 60 °C.

- **Ventilation Systems and Strategies:** Each suite has a bathroom exhaust fan and a kitchen hood fan. These fans are operated manually.

  The make-air system provides ventilation to corridors and common area rooms. There is one fan with a rated capacity of 1,180 L/s. This fan is scheduled to operate continuously. Corridor air can enter into suites through the door undercut.

- **Lighting System:** The corridor and common area lighting system includes energy efficient compact fluorescent lamps. In each suite, tenants use the conventional lamps and high intensity lighting fixtures. The exterior lighting system uses energy efficient fixtures.

- **Appliances and Other Systems:** The laundry room is located in the basement which contains four sets of washer and dryer equipment. Each suite has four major appliances such as stoves, refrigerator, dishwasher and microwave. Most suites have one television set and a stereo system.

- **Metering:** The building bulk metered for electricity, natural gas and water use.

2. AIR LEAKAGE AND VENTILATION SYSTEMS

2.1. AIR LEAKAGE TEST

The air leakage characteristics of the building envelope was determined using the whole building airtightness tests. The whole building airtightness tests were conducted using the test protocol developed by National Research Council for CMHC[2]. The airtightness test results were evaluated using the analytical procedures described in the CGSB Standard 149.10.[3]

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[2] CMHC 1990 **Establishing the protocols for measuring air leakage and air flow patterns in high-rise apartment buildings.** Prepared by R.J Magee and C Y. Shaw of IRC/NRC for CMHC, Ottawa

[3] CGSB 1988. **CGSB Standard 149.10 (new draft - 1994) — Determination of Airtightness of Building Envelopes by the Fan Depressurization Method**, Canadian General Standards Board, Ottawa, Ontario

For conducting the airtightness test, two blower doors were set up in the building. The airtightness characteristics were as follows:

Table 1: Air leakage characteristics of the test building.

C, L/(s.Pa^n)	166.078	L/(sPa^n)
n	0.669	
ACH at ΔP of 50 Pa	4.1	ac/hr
ELA at ΔP 10 Pa	3,114	cm^2
Airtightness	2.56	L/sm^2 at 50 Pa
	3.35	L/sm^2 at 75 Pa

2.2. AIR CHANGE RATE TEST

The air change rate was determined in three units using the passive sampling devices (PFT) for a period of one week. Table 2 shows the normal air change rate measured during the one week period. The air change rate includes effects of both the natural air change due to the air leakage and the mechanical ventilation in the building. It should be noted that the windows in all units were closed during the testing.

Table 2: Air change rate determined using the PFT sampling.

Building	Unit	Result (ACH)
Toronto 'S'	103	1.06 ± 0.16
	205	0.71 ± 0.1
	306	0.86 ± 0.08

2.3. CORRIDOR MAKE-UP AIR SYSTEM

The purpose of the measurements of the corridor make-up air flows were to determine the performance of make-up air ventilation system. Table 3 shows the air flow measurements. At the time of testing, make-up air fans delivered a total of 830 L/s. The design capacity of make-up air system is about 1,180 L/s.

Table 3: Measurements of corridor make-up air flows.

Building	Floor	Measured Air Flow (L/s)
Toronto 'S'	1st	255
	2nd	280
	3rd	295

The air supply to suites from the corridor through the apartment door was found to be as follows:

Table 4: Air supplied to suites from apartment door undercut.

Building	Unit	Measured Air Flow (L/s)
Toronto 'S'	103	19
	205	27
	306	15

2.4. KITCHEN AND BATHROOM EXHAUST FANS

The air flow rates were measured for kitchen and bathroom exhaust fans in the test units. As shown in Table 5, the kitchen and bathroom fans significantly under performed. The fan ratings showed that the bathroom fan was designed to provide 25 L/s (50 CFM) and the kitchen fan to provide 40 L/s (80 CFM). The reason for the under performance of these fans was not investigated.

Table 5: Air flow measurements of kitchen and bathroom fans.

		Kitchen		Bathroom
Building	Unit	Flow (High) (L/s)	Flow (Low) L/s	Flow (L/s)
Toronto 'S'	103	19		16
	205	35		21
	306	26		23

3. INDOOR ENVIRONMENT PARAMETERS

3.1. OCCUPANT SURVEY

A questionnaire was distributed to each tenant in the building. Questions were designed to determine the opinions of tenants with regard to the performance of the building and status of the indoor air quality. The sample questionnaire, both in English and French, is provided in Appendix B. Questions pertained to:

- the performance of the building in terms of indoor air quality, odour and moisture control;
- the use of the building including the presence of pets and smokers, and time spent at home; and
- general health including identification of asthma and allergies.

The survey questionnaire was distributed to all 17 apartments. Completed survey forms were returned by 13 tenants. The response rate was about 76%.

The number of tenants occupying each suite was between 1 and 2, with an average of 1.2. Majority of tenants found the indoor air quality satisfactory. Window condensation was not observed in units. It appears that those who are not satisfied with the temperature are also more likely to be unsatisfied with the air quality and the humidity, and to attribute health problems to the building air. There does not appear to be a correlation between detection of odours and dissatisfaction with other aspects of the indoor air, neither does there appear to be any correlation between the presence of smokers or pets and complaints regarding indoor air quality.

3.2. INDOOR AIR TEMPERATURE

Indoor air temperatures were measured in three suites for a period of one week beginning on November 27, 1995 to December 4, 1995 using a continuous data logger. Data was collected at 10 minute intervals.

Figure 1 shows a typical profile of the indoor air temperature in an occupied unit. Figure 2 shows the histogram of the measured temperature readings in the building. As shown, more than 80% of the time, in this unit, the indoor air temperature remained below 25.3 °C.

The measurements in three units can be summarized as follows:

- Mean temperatures varied between 22.9 and 25.6 °C.
- The maximum temperature recorded was 27 °C and the minimum temperature recorded was 20.9 °C, a difference of 6.1 °C. The differences in temperature between the recorded maximum and the minimum in each apartment were 2.2 and 3.5 °C. The apartment with the highest recorded maximum was also the apartment with the highest recorded minimum.

Figure 1: Profile of indoor air temperature in a test suite.

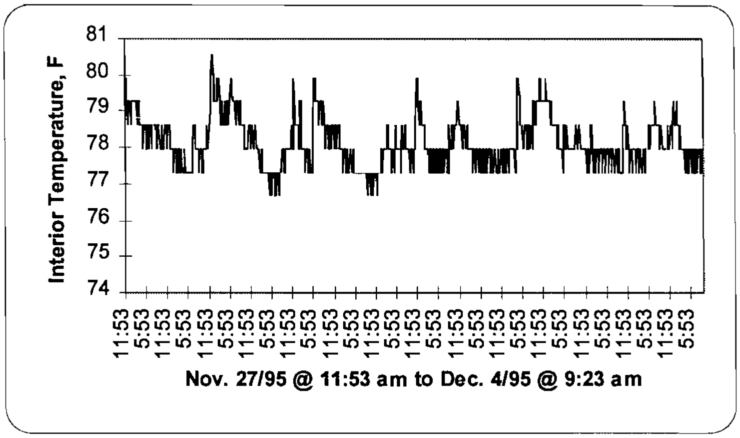
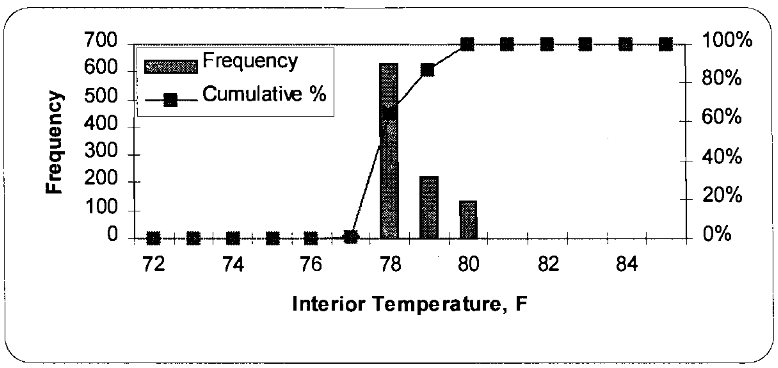


Figure 2: Frequency distribution of indoor air temperature in the test suite.



- Temperatures in apartment 306 were typically between 21.9 and 23 °C. Temperatures typically varied about 1.7 °C per day, but were found to vary by as much as 3.3 °C in apartment 306.

From the above measured data, it is shown that the average temperature in the building remained at around 23 °C. The outdoor conditions did affect the indoor temperatures. During the sunny days, the indoor temperature was about 3 °C higher than the nighttime values.

3.3. RELATIVE HUMIDITY

The relative humidity readings were taken in three suites for a period of one week beginning on November 27, 1995 to December 4, 1995 using a continuous data logger. Data was collected at 10 minute intervals. Figure 3 shows a typical profile of the indoor relative humidity in an occupied unit. Figure 4 shows the histogram of the measured relative humidity readings in the building. As shown, more than 80% of the time, in this unit, the indoor relative humidity remained within 10 to 20% range.

The measurements in three units can be summarized as follows:

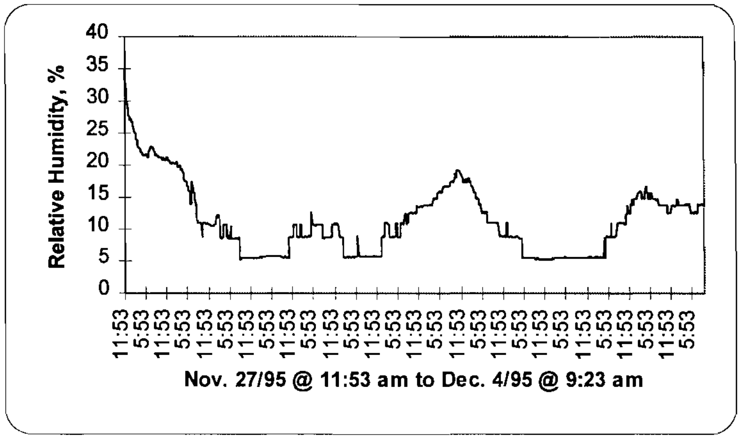
- Mean RH ranged between 11.3 and 23.1 %.
- The maximum RH recorded was 40.7 % and the minimum was 5.2 %, a difference of 35.5 %. The differences in RH between the recorded maximum and the recorded minimum in each

apartment were 30.3 and 30.8 %. The apartment with the highest recorded maximum was also the apartment with the highest recorded minimum.

- RH varied by approximately 20 % in any given day in apartment 306, but were mostly between 15 and 25 %. RH varied by approximately 5 % in any given day, but occasionally 15 %, in apartment 103. RH was mostly between 5 and 15 %, and most of those were between 5 and 10 %, in apartment 103.

From the above measured data, it is shown that the average relative humidity in the building ranged from about 10% to 20% with an overall average of about 15%. At the time of the monitoring, this level of relative humidity was low for maintaining the occupant comfort.

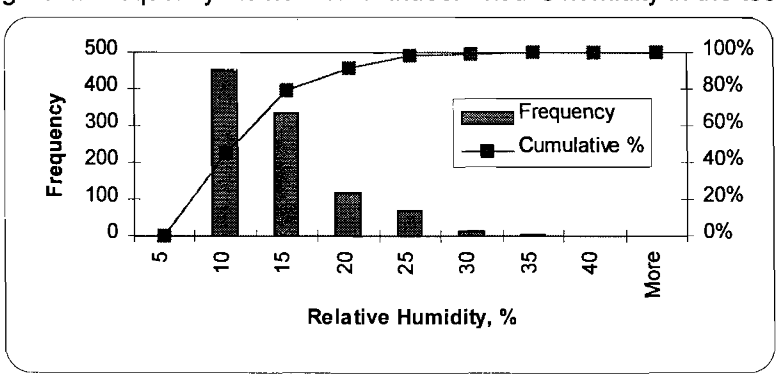
Figure 3: Profile of indoor relative humidity in a test suite.



3.4. CARBON DIOXIDE

The carbon dioxide readings were taken in three suites for a period of one week beginning on November 27, 1995 to December 4, 1995 using a continuous data logger. Data was collected at 10 minute intervals. Figure 5 shows a typical profile of the carbon dioxide in an occupied unit. Figure 6 shows the histogram of the measured carbon dioxide readings in the building. As shown, almost all of the time, in this test unit, the carbon dioxide levels remained below 800 ppm. The average CO_2 levels were about 550 ppm which is much lower than recommended levels of about 1,000 ppm.

Figure 4: Frequency distribution of indoor relative humidity in the test suite.



Levels in apartment 103 typically fluctuated by about 300 ppm every day, with the majority of readings at approximately 500 ppm. Levels were typically about 400-450 ppm in apartment 205. Levels in apartment 306 were usually about 600 ppm; they fluctuated, both up and down, by about 200 ppm in a day, or as much as 900 ppm.

From the above measured data, it is shown that the average CO_2 levels in the building were significantly lower than 1,000 ppm in all units. At the time of the monitoring, these levels of carbon dioxide levels were acceptable for maintaining the occupant comfort.

Figure 5: Profile of carbon dioxide levels in a test suite.

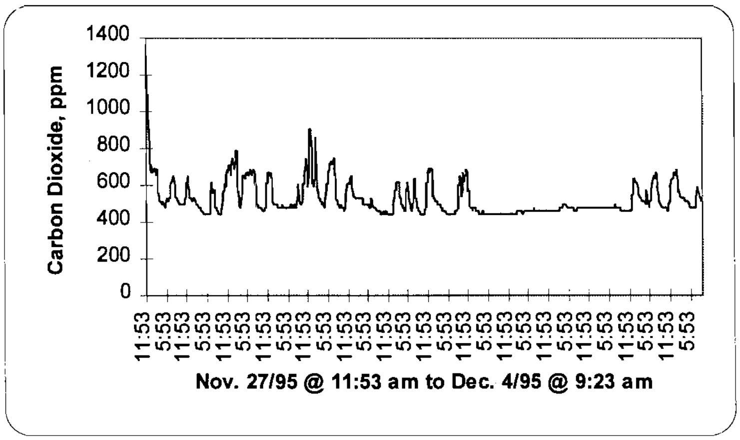
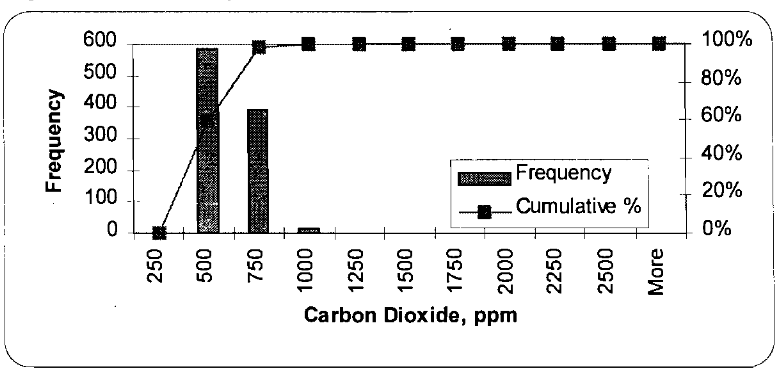


Figure 6: Frequency distribution of carbon dioxide levels in a test suite.



3.5. CARBON MONOXIDE

In this building, the carbon monoxide levels in the two suites ranged from negligible values to a maximum value of about 2 ppm. In the unit 205, the recorded level was 50 ppm which we believe is due to the faulty data logger. Gaztek CO detectors were used to confirm the instantaneous values in this apartment which indicated only trace levels of CO. The higher levels of carbon monoxide in this building is still significantly lower than the maximum allowable value of 11 ppm.

3.6. ELECTROMAGNETIC FIELDS (EMFS)

The intensity of electromagnetic fields were measured in some suites. The electromagnetic fields were measured with and without power turned on in the living area. As shown in the following Table 6, the EMF readings were well below recommended levels of 8 milligauss in this building.

Table 6: Electromagnetic fields in suites with and without power on.

		Living Room (milligauss)		Master Bedroom (milligauss)		Kitchen (milligauss)		Bathroom (milligauss)	
Building	Unit	with	without	with	without	with	without	with	without
Toronto 'S'	103	2 09		2.13		2.14		2.08	
	205	2 88		2.44		2.75		2.34	
	306	2.13		1.68		1.42		2.16	

3.7. VOLATILE ORGANIC COMPOUNDS (VOCs)

The VOCs were sampled in three apartment units for a period of one week. Table 7 shows the traces of some VOC compounds in the building. For detailed VOC analysis, unit 205 was chosen because low air changes were measured and the higher levels of CO_2. The measured levels of VOCs are significantly lower than the target level of 1 mg/m^3 for acceptable indoor air quality.

3.8. FORMALDEHYDE

Two AQR dosimeters were placed in 3 apartment units for a period of seven days. The formaldehyde levels were about 0.01, 0.02 and 0.02 ppm in Unit 103, 205 and 306 respectively. The formaldehyde levels were significantly lower than action level of 0.10 ppm suggested by Health Canada.

Table 7: Volatile Organic Compounds in the test building.

	Unit	Target Compound	Result (mg/m^3)
Toronto 'S'	103	TVOC	0.093
	205	benzene	0.002
		toluene	0.005
		ethylbenzene	0.001
		m-p xylenes	0.001
		o-xylenes	0.001
		dichlorobenzene	0.015
		d-limonene	0.024
	306	TVOC	0.17

3.9. LIGHTING LEVELS

Lighting levels were measured in common area and corridors. Table 8 summarizes the average levels of lighting in the building.

Table 8: Lighting levels in the common area of building.

Common Area	Lighting Level (foot candles)
Corridors	5-20
Front Lobby	10
Elevators	
Elevator Lobbies	
Stairwells	
Laundry Room	20-55
Recreation Room	5-50

4. ENERGY PERFORMANCE OF THE BUILDING

The energy performance of the building was evaluated using the DOE-2.1E energy simulation program. Data input files for the energy simulation programs were created using the field survey of various components, equipment and systems, and using the architectural drawings of the building.

4.1. UTILITY BILLS

The space heating in suite is accomplished using a central hydronic heating system. The make-up air is heated with natural gas. The domestic hot water is provided by a central hydronic boiler. The building is bulk metered for electricity, natural gas and water consumption. The annual energy use totals were developed using the electricity and natural gas bills. Utility bills were available for the full year of 1993 and part year of 1994. Energy analysis was therefore performed for the year 1993.

4.2. ENERGY ANALYSIS RESULTS

A detailed energy analysis was undertaken to evaluate the energy performance of the building. DOE-21.E input data files were prepared and were simulated using the Toronto weather files for the 1993.

The hourly energy analysis showed that the annual heat losses during the heating season accounted for a total of 124.2 MWh. Heat loss components are shown in Figure 7. Conduction heat losses through walls accounted for 25.6 MWh (20.6%). Roof and below grade components accounted for 10.2 MWh (8.2%) and 8.8 MWh (7.1%) respectively. Heat losses through windows accounted for about 44 MWh (35.4%) annually. The mechanical ventilation in the building accounted for 14.9 MWh (12%). The air leakage heat losses were about 20.7 MWh (16.7%).

The heat gains in the building includes solar and internal gains. The internal gains are sensible heat gains due to occupancy, lighting, hot water and other energy consuming equipment. As shown in Figure 9, the total heat gains during the heating season were about 124.2 MWh. Solar gains accounted for 11.2 MWh (9%) of energy for offsetting the purchased energy requirements for the building. The internal gains were about 20.7 MWh or 16.7% of the total. The purchased space heating energy was about 92.3 MWh or 74.4% of the total energy requirements in the building.

The DOE-2.1E simulation for the weather year showed that the total energy requirement for September 1994 to August 95 is about 187 MWh. The energy use profile is shown in Figure 10. As shown in the figure, the lighting energy use is about 11.8% of the total. Space heating energy use accounted for 48.3% of the total energy use in the building. As shown in Table 9 and Table 10, the energy consumption profiles compared well with the measured utility data for two years of utility data.

Figure 8 shows the energy cost balance sheet for the building. It can be seen from the balance sheet that energy use for space heating and domestic hot water accounts for more than 50% of the purchased energy costs. Energy conservation measures aimed at reducing the hot water use in the building and space heating controls can improve the energy efficiency. The electricity use for common area lighting and other appliances also constitute somewhat high cost expenditure.

Figure 7: Heat loss components.

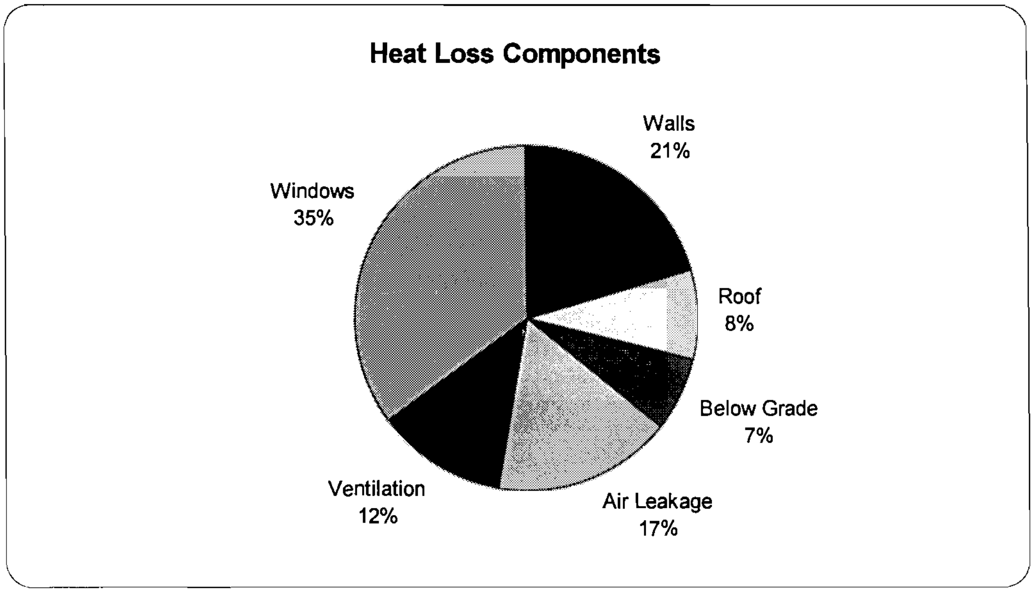


Table 9: Summary of estimates and actual use of electricity in the building.

Year	Electricity (kWh) Common Areas	Electricity (kWh) Apartments	Total Electricity (kWh)	Total Electricity DOE2.1e (kWh)
1994-95			51,040	49,871

Table 10: Summary of estimates and actual use of natural gas in the building.

Year	Actual Gas Use(GJ)	Estimated Gas Use DOE21.e (GJ)
1994-95	489.8	508.8

Figure 8: Energy cost balance sheet for the building (based on DOE-2.1E estimates).

Year 1994-95

Cost of Energy Supply			Cost of Energy Use		
Solar Gains	$ 302	3 8%	Walls, Roof and Below Grade	$ 1,208	15.3%
Internal Gains	$ 560	7.1%	Windows and Exterior Doors	$ 1,191	15 0%
Space Heating	$ 2,501	31.6%	Air Leakage	$ 560	7.1%
DHW	$ 1,217	15.4%	Ventilation	$ 404	5 1%
Base Use	$ 3,342	42 2%	DHW+Base Use	$ 4,559	57 5%
Estimated Energy Supply Cost	**$ 7,922**		**Estimated Cost of Energy Use**	**$ 7,922**	

Figure 9: Components of heat gains in the building.

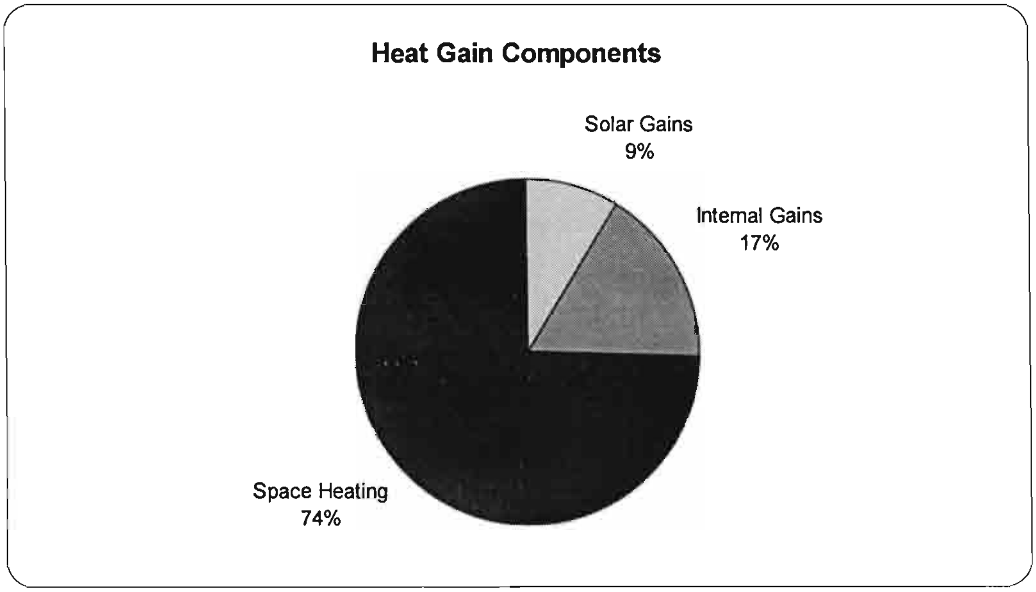
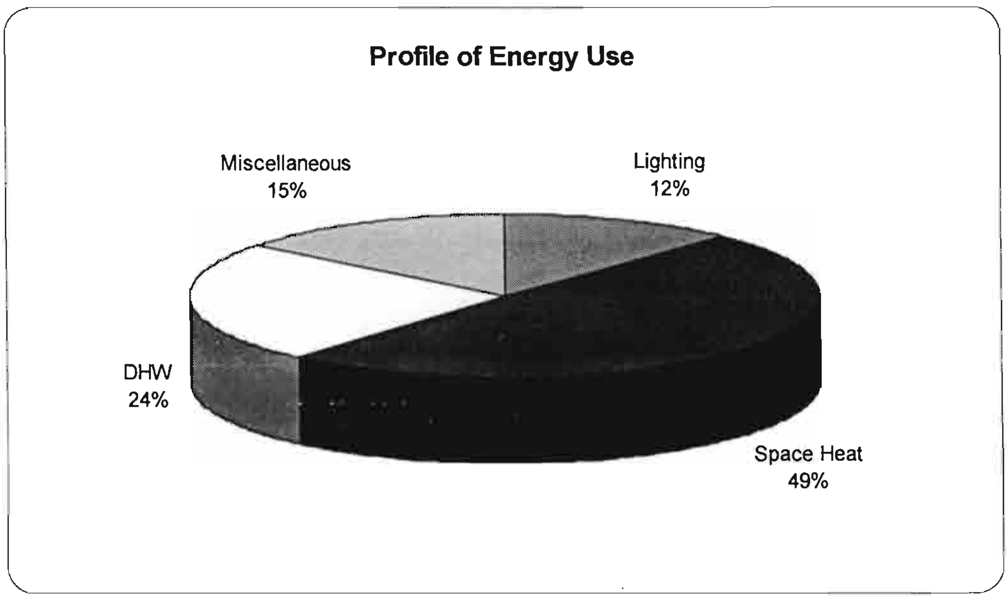


Figure 10: Profile of energy use in the building.



5. DISCUSSION AND COMMENTS

The following comments pertain to the building performance and comparisons with appropriate required construction practices:

- The field survey showed that the building is well kept and well maintained. The airtightness test showed that the envelope air leakage is about 3.35 L/s.m^2 at 75 Pa pressure difference. The airtightness value is significantly higher than what can be expected in buildings with air barrier systems. This building generally satisfies the thermal characteristics of envelope components as per the 1990 Ontario Building Code.

- The ventilation system provides adequate fresh air flows to corridors. The corridor air leading to suites ranged from 15 to 27 L/s. The entry of make-up ventilation air in suites have kept the CO_2 levels and formaldehyde levels significantly low. It seems that there is just sufficient amounts of ventilation air is introduced in the suites. Our review of the ventilation system showed that the building design meets the intent of the 1990 OBC for providing required natural or mechanical ventilation requirements. The actual performance monitoring showed that the ventilation systems (natural and mechanical) did perform as per the minimum requirements for human comfort as per the CSA F-326.
- The annual purchased energy in the building is about 219.5 kWh/m^2 (20.4 kWh/ft^2) of the floor space. About 48% of the total annual energy is attributed to the space heating requirements and 24% of annual energy use is for domestic hot water needs.

Appendix A-5: Vancouver 'LV' Building

Building Report

ENERGY USE AND INDOOR AIR QUALITY IN MID-RISE APARTMENT BUILDINGS

Field Investigation and Energy Analysis Report

Appendix A-5: Vancouver 'LV' Building

1. FIELD SURVEY

The subject building is a 4-storey apartment building located in Vancouver. It is owned and operated by B.C. Housing Foundation. The building construction was completed in 1992 and occupancy started just after that within couple of months all suites were fully occupied. The subject building is a part of two buildings forming the housing development. The bulk metering of electricity, natural gas and water is for the whole project consisting of two buildings which are identical in all respect. It is a rectangular building. The building is surrounded on one side by other identical building but the other elevations are exposed. At the time of the field survey, the building was fully occupied. As part of the project, a detailed field survey was undertaken and an inventory of energy consuming equipment and systems was prepared. The field survey included the data collection of building and systems information required for hourly energy simulation using the DOE-2.1E. The indoor environment survey was conducted using test protocols which are described in Appendix B.

The following briefly describes various building characteristics:

- **Building Layout:** The main entrance of this building is facing east direction. The gross floor area of the building is approximately 3,060 m^2. There are 45 one-bedroom apartments (4 different layouts).

  Common areas and their approximate sizes include a meeting room and lounge (69 m^2), a storage room (5 m^2), an amenity room (38 m^2), and an office on the ground floor, a laundry room (21 m^2) on the second floor, a tenant workshop (21 m^2) and a mechanical room (21 m^2) on the fourth floor, and an electrical/mechanical and room (102 m^2), a bicycle storage room (44 m^2), a garbage room (22 m^2), and a maintenance room (12 m^2) in the basement. The total area of common spaces, not including corridors and lobbies, is approximately 360 m^2. Underground parking is linked to the underground parking of the adjacent building in the development.

  According to the building superintendent, all suites are occupied. The majority of occupancy is for seniors. Indoor air quality tests were conducted in three apartments: 111, 301, and 404.

- **Building Envelope:** This is a 4-storey wood frame apartment building. The exterior walls consist of 90 mm face brick, 25 mm air space, 37 mm glassclad, 13 mm exterior grade gypsum board, 2x4 wood studs @ 300 o.c., R-12 fiberglass batt insulation, 6 mil poly vapour barrier and 13 mm gypsum wall board. The wood studs cover approximately 24% of the area. The effective thermal resistance of the wall assembly was estimated to be about RSI 2.52.[1]

  The attic consists of R-32 insulation. The effective thermal resistance of the roof assembly was estimated to be about RSI 3.25.

[1] The effective thermal resistance of the envelope assembly was determined using the DOE-2.1E program's material and component library.

There are several sizes of windows in the building. About 30% of windows are double-glazed picture windows with thermally broken aluminum framing. The other 70% are double sliders. The field survey showed that the weatherstripping on theses windows was in good acceptable condition. It was also reported by the superintendent that some tenants keep their windows open even during winter months.

The basement level of the building is unfinished from inside. The below grade concrete walls are 200 mm thick and have not been insulated. The underground parking is not insulated.

- **Space Heating System:** The space heating system consists of a central gas-fired hydronic system with radiant floor heating in each suite. There are two gas-fired boilers to meet the space heating requirements. One is rated at 462 MBtu (135 kW) and other at 396 MBtu (116 kW). Two hydronic system circulating pumps, each rated at 2 hp, deliver the hot water to the radiant floors. The hydronic circuits are controlled by indoor/outdoor temperature controllers.

  The forced-air make-up air system is provided for the corridor and common area ventilation. The make-up air is heated using the natural gas heater. The furnace is rated at 300 MBtu (kW). There are two fresh air risers in the building with two fans each with a capacity to provide 3,600 CFM (1,793 L/s) of air. The make-up air fan runs continuously. The heating capacity of gas heater is controlled by a supply air thermostat.

- **Domestic Hot Water System:** There is a central domestic water system in the building. There are two gas-fired domestic hot water boilers each rated at 360 MBtu (105 kW). There are two hot water storage tanks. The total hot water tank capacity is about 492 L.

- **Ventilation Systems and Strategies:** Each suite has a bathroom exhaust fan and a kitchen hood fan. These fans are operated manually.

  The make-air system provides ventilation to corridors and common area rooms. There are two fans each rated at 1,793 L/s. This fan is scheduled to operate continuously. Corridor air can enter in to suites through the door undercut and door.

- **Lighting System:** The corridor and common area lighting system includes energy efficient compact fluorescent lamps. In each suite, tenants use the conventional lamps and high intensity lighting fixtures. The exterior lighting system uses energy efficient fixtures.

- **Appliances and Other Systems:** Laundry room is located in the basement which includes four sets of washer and dryer equipment. Each suite has four major appliances such as stoves, refrigerator, dishwasher and microwave. Most suites have one television set and a stereo system.

- **Metering:** Tenants are metered individually for electricity; the building is bulk metered for gas and is also metered for electricity use in common areas.

2. AIR LEAKAGE AND VENTILATION SYSTEMS

2.1. AIR LEAKAGE TEST

The air leakage characteristics of the building envelope was determined using the whole building airtightness tests. The whole building airtightness tests were conducted using the test protocol

developed by National Research Council for CMHC[2]. The airtightness test results were evaluated using the analytical procedures described in the CGSB Standard 149.10.[3]

For conducting the airtightness test, two blower doors were setup in the building. The airtightness characteristics were as follows:

Table 1: Air leakage characteristics of the test building.

C, L/(s.Pa^n)	511.122 L/(sPa^n)
n	0.633
ACH at ΔP of 50 Pa	2.94 ac/hr
ELA at ΔP 10 Pa	8,829 cm^2
Airtightness	2.34 L/sm^2 at 50 Pa
	3.03 L/sm^2 at 75 Pa

2.2. AIR CHANGE RATE TEST

The air change rate was determined in one unit using the passive sampling devices (PFT) for a period of one week. Table 2 shows the normal air change rate measured during the one week period. The air change rate includes effects of both the natural air change due to the air leakage, inter zone air movement and the mechanical ventilation in the building. It should be noted that the windows in all units were closed during the testing.

Table 2: Air change rate determined using the PFT sampling.

Building	Unit	Result (ACH)
Vancouver 'LV'	111	0.09 ± 0.01

It seemed that the PFT concentrations in this building was significantly lower than other buildings which means that the ventilation rate was also lower. It is felt that the results of the air change rate may not be accurate due, perhaps, to contamination of the sampler by the source either prior to or after the test period.

2.3. CORRIDOR MAKE-UP AIR SYSTEM

The purpose of the measurements of the corridor make-up air flows were to determine the performance of make-up air ventilation system. Table 3 shows the air flow measurements. At the time of testing, make-up air fans delivered a total of 2,165 L/s. The design capacity of make-up air system is about 3,586 L/s.

Table 3: Measurements of corridor make-up air flows.

Building	Floor	Measured Air Flow (L/s)
Vancouver 'LV'	1st	450
	2nd	479
	3rd	602
	4th	634

The air supply to suites from the corridor through the apartment door was found to be as follows:

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[2] CMHC 1990. **Establishing the protocols for measuring air leakage and air flow patterns in high-rise apartment buildings.** Prepared by R J Magee and C Y Shaw of IRC/NRC for CMHC, Ottawa.

[3] CGSB 1988 **CGSB Standard 149.10 (new draft - 1994) — Determination of Airtightness of Building Envelopes by the Fan Depressurization Method**, Canadian General Standards Board, Ottawa, Ontario

Table 4: Air supplied to suites from apartment door undercut.

Building	Unit	Measured Air Flow (L/s)
Vancouver 'LV'	111	1
	301	1
	404	0

2.4. KITCHEN AND BATHROOM EXHAUST FANS

The air flow rates were measured for kitchen and bathroom exhaust fans in the test units. As shown in Table 5, the kitchen and bathroom fans performed well. The fan ratings showed that the bathroom fan was designed to provide 100 L/s (200 CFM) and the kitchen fan to provide 100 L/s (200 CFM).

Table 5: Air flow measurements of kitchen and bathroom fans.

		Kitchen		Bathroom
Building	Unit	Flow (High) (L/s)	Flow (Low) L/s	Flow (L/s)
Vancouver 'LV'	111	75	56	79
	301	86	58	79
	404	91	67	108

3. INDOOR ENVIRONMENT PARAMETERS

3.1. OCCUPANT SURVEY

A questionnaire was distributed to each tenant in the building. Questions were designed to determine the opinions of tenants with regard to the performance of the building and status of the indoor air quality. The sample questionnaire, both in English and French, is provided in Appendix B. Questions pertained to:

- the performance of the building in terms of indoor air quality, odour and moisture control;
- the use of the building including the presence of pets and smokers, and time spent at home; and
- general health including identification of asthma and allergies.

The survey questionnaire was distributed to all 47 apartments. Completed survey forms were returned by 25 tenants. The response rate was about 53%.

The number of tenants occupying each suite was between 1 and 2, with an average of 1.1. A significant number of tenants, that is approximately 50%, do not appear to be satisfied with the indoor air quality. The majority of problems seem to be attributable to summer humidity levels and general air quality (stuffy, stale or drafty). There were relatively few complaints (20%) with regard to winter relative humidity, and even fewer tenants had condensation on the windows in the winter (4%). Identification of odours was expressed by 20% of the tenants responding; 28% of respondents attributed health problems to the building There is no apparent correlation between the presence of odours or health problems attributable to the building and complaints about the general air quality.

3.2. INDOOR AIR TEMPERATURE

Indoor air temperatures were measured in three suites for a period of one week beginning on November 15, 1995 to November 21, 1995 using a continuous data logger. Data was collected at a 10 minutes interval.

Figure 1 shows a typical profile of the indoor air temperature in an occupied unit. Figure 2 shows the histogram of the measured temperature readings in the building. As shown, more than 80% of the time, in this unit, the indoor air temperature remained below 23 °C.

The measurements in three units can be summarized as follows:

- Mean temperatures ranged between 21.9 and 25.0 °C.
- The maximum recorded temperature was 28.7 °C and the minimum recorded temperature was 18.8 °C, a difference of 9.9 °C. The differences in temperature between the recorded maximum and the recorded minimum in each apartment were 6, 6.6 and 3.4 °C. The apartment with the highest maximum was not the apartment with the highest recorded minimum.
- Temperatures were generally between 23 and 26 °C, with daily fluctuations of about 2 or 3 °C usually in apartment 111. Daily fluctuations were between 2 and 5 °C in apartment 301. Temperatures were generally between 24 and 26 °C in apartment 404, with daily fluctuations typically between 1.5 and 3 °C.
- Temperature was monitored at three heights in apartment 404: floor-, mid- and ceiling-height; temperature at mid-height was usually higher than the other two locations, although the temperature at ceiling-height was occasionally higher.

Figure 1: Profile of indoor air temperature in a test suite.

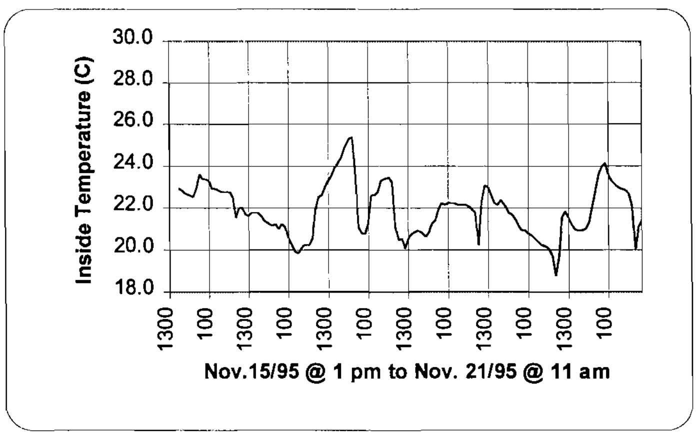
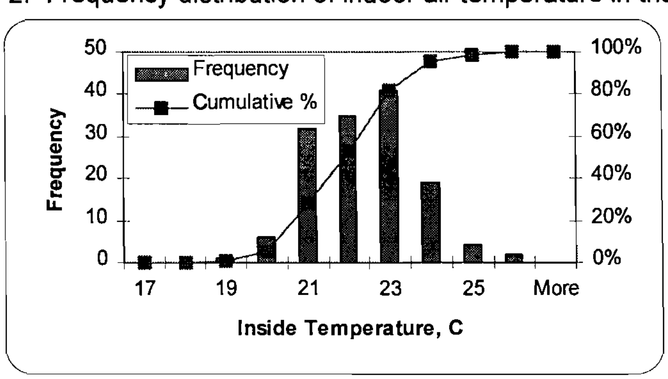


Figure 2: Frequency distribution of indoor air temperature in the test suite.



From the above measured data, it is shown that the average temperature in the building remained at around 23 °C. The outdoor conditions did affect the indoor temperatures. During the sunny days, the indoor temperature was about 3 °C higher than the nighttime values.

3.3. RELATIVE HUMIDITY

The relative humidity readings were taken in three suites for a period of one week beginning on November 15, 1995 to November 21, 1995 using a continuous data logger. Data was collected at a 10 minutes interval. Figure 3 shows a typical profile of the indoor relative humidity in an occupied unit. Figure 4 shows the histogram of the measured relative humidity readings in the building. As shown, more than 80% of time in this unit, the indoor RH remained within 30 to 45% range.

Figure 3: Profile of indoor relative humidity in a test suite.

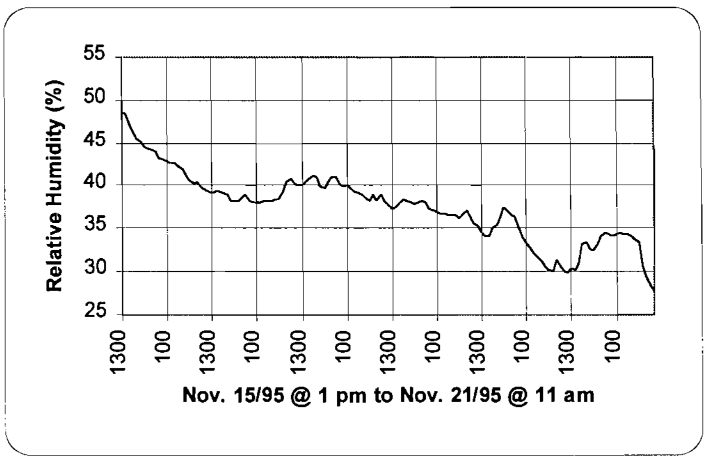
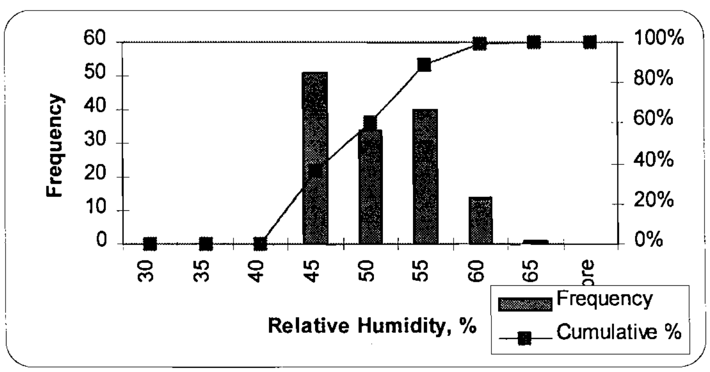


Figure 4: Frequency distribution of indoor relative humidity in the test suite.



The measurements in three units can be summarized as follows:

- Mean RH were between 34.8 and 48.0 %.
- The maximum RH recorded was 60.2 % and the minimum was 27.7 %, a difference of 32.5 %. The differences in RH between the recorded maximum and the recorded minimum in each apartment were 20.9, 19.5 and 11.3 %. The apartment with the highest recorded maximum was also the apartment with the highest recorded minimum, but the apartment with the lowest recorded maximum was <u>not</u> the apartment with the lowest recorded minimum.
- RH was mostly between 35 and 41 %, with daily fluctuations of about 2 % in apartment 111. RH was mostly between 38 and 42 %, with daily fluctuations of about 4 %; however there

were fluctuations of up to 9 %. Daily fluctuations were between 4 and 8 % in apartment 404, with most of the readings between 33 and 38 %.

From the above measured data, it is shown that the average relative humidity in the building ranged from about 30% to 45% with an overall average of about 40%.

3.4. CARBON DIOXIDE

The carbon dioxide readings were taken in three suites for a period of one week beginning on November 15, 1995 to November 21, 1995 using a continuous data logger. Data was collected at a 10 minutes interval. Figure 5 shows a typical profile of the carbon dioxide in an occupied unit. Figure 6 shows the histogram of the measured carbon dioxide readings in the building. As shown, almost all time, in this test unit, the carbon dioxide levels remained below 800 ppm. The average CO_2 levels were about 400 ppm which is much lower than recommended levels of about 1,000 ppm.

CO_2 generally fluctuated between 350 and 500 in apartment 111, with daily fluctuations of about 150, but were as high as 350 ppm. CO_2 was mostly around 400 ppm, fluctuating up to approximately 575 ppm in apartment 301; daily fluctuations were about 200 or 220 ppm. Daily fluctuations in apartment 404 were approximately 400 or 450 ppm; readings typically went from high to low, with no "typical" values to note.

From the above measured data, it is shown that the average CO_2 levels in the building were significantly lower than 1,000 ppm in all units. At the time of the monitoring, these levels of carbon dioxide levels were acceptable for maintaining occupant comfort.

Figure 5: Profile of carbon dioxide levels in a test suite.

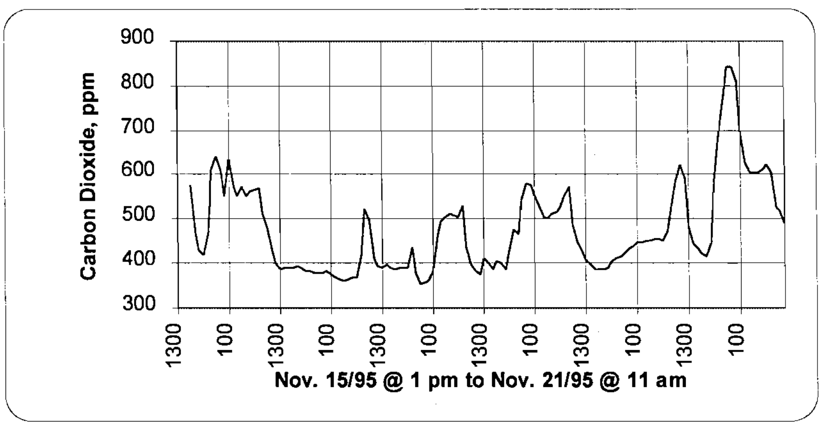
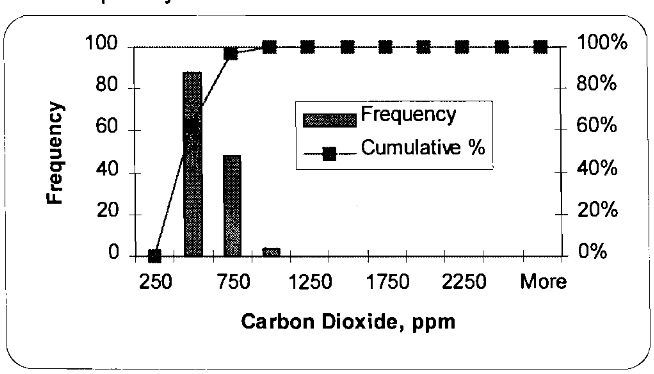


Figure 6: Frequency distribution of carbon dioxide levels in a test suite.



3.5. CARBON MONOXIDE

In this building, the carbon monoxide levels in the three suites ranged from negligible values to a maximum value of about 2 ppm. The higher levels of carbon monoxide in this building is still significantly lower than the maximum allowable value of 11 ppm.

3.6. ELECTROMAGNETIC FIELDS (EMFS)

The intensity of electromagnetic fields were measured in some suites. The electromagnetic fields were measured with and without power turned on in the living area. As shown in the following Table 6, the EMF readings were well below recommended levels of 8 milligauss in this building.

Table 6: Electromagnetic fields in suites with and without power on.

		Living Room (milligauss)		Master Bedroom (milligauss)		Kitchen (milligauss)		Bathroom (milligauss)	
Building	**Unit**	**with**	**without**	**with**	**without**	**with**	**without**	**with**	**without**
Vancouver 'LV'	111	2.21	2.20	2.20	2.38	2.02	1.92	2 19	2 07
	301	0.22	0.25	0 20	0 27	0 26	0.19	0.34	0 27
	404	0 78	0 31	0 36	0.35	0 64	0 60	0.46	0 38

3.7. VOLATILE ORGANIC COMPOUNDS (VOCS)

The VOCs were sampled in three apartment units for a period of one week. Table 7 shows the traces of some VOC compounds in the building. For detailed analysis, unit 111 was chosen because low air changes and relatively higher levels of CO_2. The measured levels of VOCs are significantly lower than the target level of 1 mg/m^3 for acceptable indoor air quality in residences.

3.8. FORMALDEHYDE

Two AQR dosimeters were placed in one apartment unit for a period of seven days. The formaldehyde levels were about 0.02, 0.025 and 0.02 ppm in Unit 111, 301 and 404 respectively. The formaldehyde levels were significantly lower than action level of 0.10 ppm suggested by Health Canada.

Table 7: Volatile Organic Compounds in the test building.

	Unit	Target Compound	Result (mg/m^3)
Vancouver 'LV'	111	toluene	0.06
		xylenes	0.07
		benzenes	0.10
	301	TVOC	0.14
	404	TVOC	0.21

3.9. LIGHTING LEVELS

Lighting levels were measured in common area and corridors. Table 8 summarizes the average levels of lighting in the building.

Table 8: Lighting levels in the common area of building.

Common Area	Lighting Level (foot candles)
Corridors	2
Front Lobby	6
Elevators	20
Elevator Lobbies	3
Stairwells	50
Laundry Room	170
Recreation Room	

4. ENERGY PERFORMANCE OF THE BUILDING

The energy performance of the building was evaluated using the DOE-2.1E energy simulation program. Data input files for the energy simulation programs were created using the field survey of various components, equipment and systems, and using the architectural drawings of the building.

4.1. UTILITY BILLS

The space heating in suite is accomplished using central hydronic heating system. The make-up air is heated with natural gas. The domestic hot water is provided by a central hydronic boiler. The building is bulk metered for electricity, natural gas and water consumption. The annual energy use totals were developed using the electricity and natural gas bills. Utility bills were available for the full year of 1993 and part year of 1994. Energy analysis was therefore performed for the year 1993.

4.2. ENERGY ANALYSIS RESULTS

A detailed energy analysis was undertaken to evaluate the energy performance of the building. DOE-21.E input data files were prepared and were simulated using the Vancouver weather files for the year 1994.

The hourly energy analysis showed that the annual heat losses during the heating season accounted for a total of 113.8 MWh. Heat loss components are shown in Figure 7. Conduction heat losses through walls accounted for 33 MWh (29%). Roof and below grade components accounted for 7.3 MWh (6.4%) and 6.4 MWh (5.6%) respectively. Heat losses through windows accounted for about 29.7 MWh (26.1%) annually. The mechanical ventilation in the building accounted for 12.9 MWh (13%). The air leakage heat losses were about 22.5 MWh (19.7%).

The heat gains in the building includes solar and internal gains. The internal gains are sensible heat gains due to occupancy, lighting, hot water and other energy consuming equipment. As shown in Figure 8, the total heat gains during the heating season were about 113.8 MWh. Solar gains accounted for 10.2 MWh (9%) of energy for offsetting the purchased energy requirements for the building. The internal gains were about 11.9 MWh or 10.5% of the total. The purchased space heating energy was about 91.6 MWh or 80.5% of the total energy requirements in the building.

The DOE-2.1E simulation for the weather year showed that the total energy requirement for the year 1994 was about 444 MWh. The energy use profile is shown in Figure 9. As shown in the figure, the lighting energy use is about 22.8% of the total. Space heating energy use accounted for 20.6% of the total energy use in the building. As shown in Table 9 and Table 10, the energy consumption profiles compared within 5% with the measured utility data for a year of utility data.

Figure 7: Heat loss components.

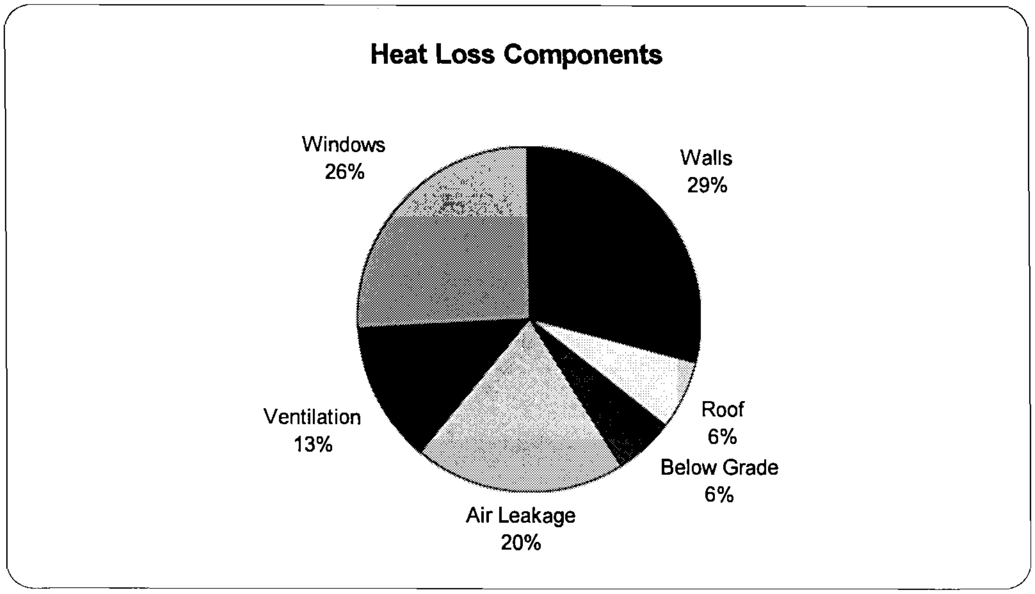


Table 9: Summary of estimates and actual use of electricity in the building.

Year	Electricity (kWh) Common Areas	Electricity (kWh) Apartments	Total Electricity (kWh)	Total Electricity DOE2.1e (kWh)
1994	113,400	142,941	256,341	263,735

Table 10: Summary of estimates and actual use of natural gas in the building.

Year	Actual Gas Use(GJ)	Estimated Gas Use DOE21.e (GJ)
1994	981.5	997.9

Figure 8: Components of heat gains in the building.

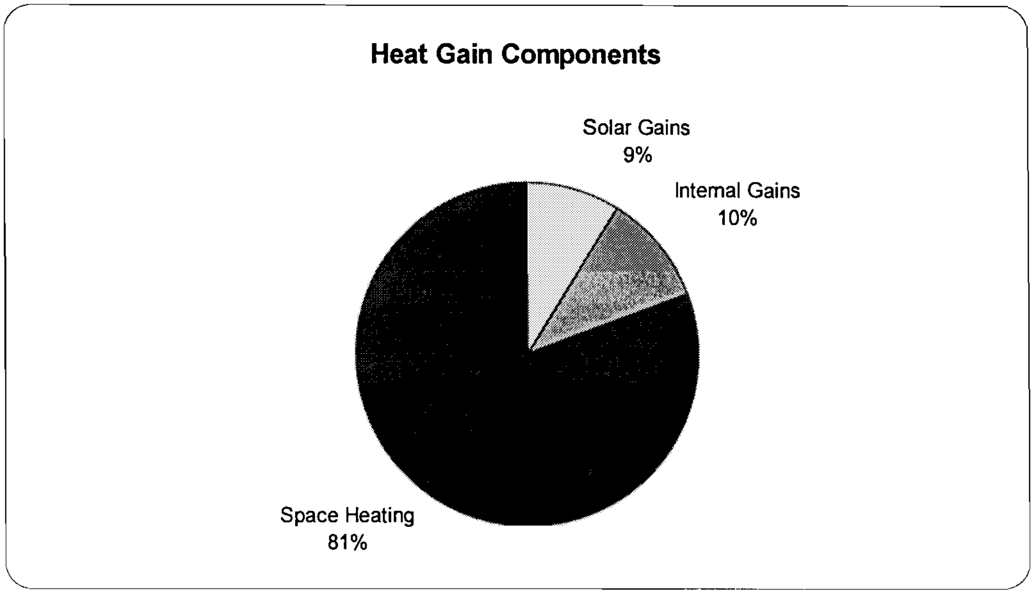


Figure 9: Profile of energy use in the building.

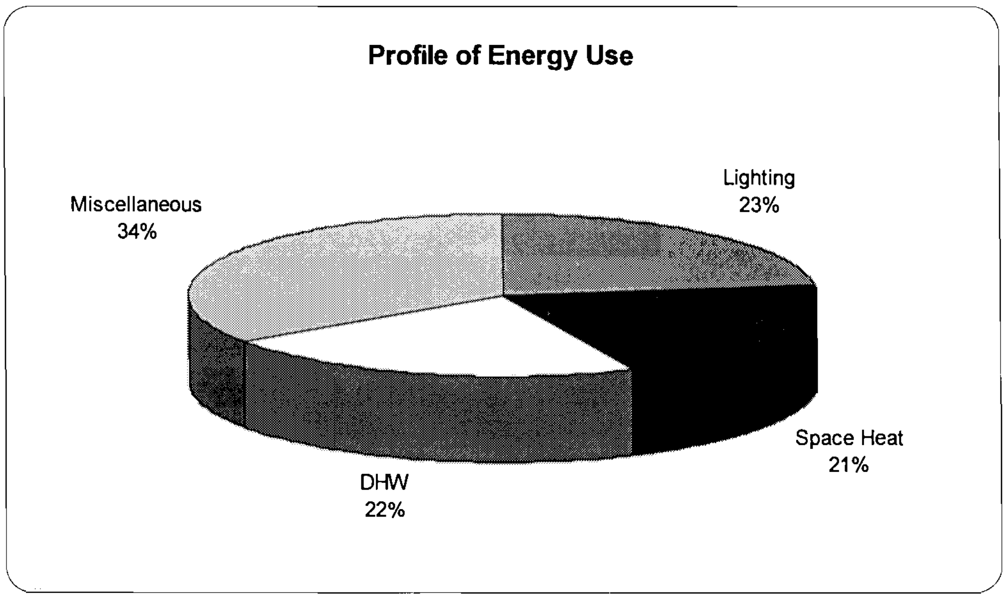


Figure 10: Energy cost balance sheet for the building (based on DOE-2.1E estimates).

Year 1994

Cost of Energy Supply			Cost of Energy Use		
Solar Gains	$ 243	1.2%	Walls, Roof and Below Grade	$ 1,108	5 5%
Internal Gains	$ 283	1 4%	Windows and Exterior Doors	$ 704	3 5%
Space Heating	$ 2,172	10 8%	Air Leakage	$ 532	2 6%
DHW	$ 2,292	11 3%	Ventilation	$ 354	1 8%
Base Use	$ 15,206	75 3%	DHW+Base Use	$ 17,498	86 6%
Estimated Energy Supply Cost	**$ 20,196**		**Estimated Cost of Energy Use**	**$ 20,196**	

Figure 10 shows the energy cost balance sheet for the building. It can be seen from the balance sheet that energy use for space heating and domestic hot water accounts for more than 45% of the purchased energy costs. Energy conservation measures aimed at reducing the hot water use in the building can improve the energy efficiency. The electricity use for common area lighting and other appliances also constitute somewhat high cost expenditure.

5. DISCUSSION AND COMMENTS

The following comments pertain to the building performance and comparisons with appropriate required construction practices:

- The field survey showed that the building is well kept and well maintained. The airtightness test showed that the envelope air leakage is about 3.03 L/s.m^2 at 75 Pa pressure difference. The airtightness value is significantly higher than what can be expected in buildings with air barrier systems. This building generally satisfies the thermal characteristics of envelope components as per the 1990 BC Building Code.
- The ventilation system provides adequate fresh air flows to corridors. The corridor air leading to suites was negligible. The air leakage and opening of windows in the building during the test time kept the CO_2 levels and formaldehyde levels significantly low. It seems that there is sufficient amount of ventilation air is introduced in the suites. Our review of the ventilation system showed that the building meets the intent of the appropriate BC Building Code for providing required natural or mechanical ventilation requirements. The actual performance monitoring showed that the ventilation systems (natural and mechanical) did perform as per the minimum requirements as per the CSA F-326.
- The annual purchased energy in the building is about 152.8 kWh/m^2 (14.2 kWh/ft^2) of the floor space. About 20% of the total annual energy is attributed to the space heating requirements and 21% of annual energy use is for domestic hot water needs. Electrical loads (lighting, appliances, fans, etc.) accounts for 55% of total energy consumption.

Appendix A-6: Vancouver 'MV' Building

Building Report

ENERGY USE AND INDOOR AIR QUALITY IN MID-RISE APARTMENT BUILDINGS

Field Investigation and Energy Analysis Report

Appendix A-6: Vancouver 'MV' Building

1. FIELD SURVEY

The subject building is a 3-storey apartment building located in Tsawwassen, British Columbia. The building was built in 1993 as a retirement home. It is a rectangular building. At the time of the field survey, the building was fully occupied. As part of the project, a detailed field survey was undertaken and an inventory of energy consuming equipment and systems was prepared. The field survey included the data collection of building and systems information required for hourly energy simulation using the DOE-2.1E. The indoor environment survey was conducted using test protocols which are described in Appendix B.

The following briefly describes various building characteristics:

- **Building Layout:** The main entrance of this building is facing north direction. The gross floor area of the building is approximately 3,268 m^2. There are 45 one-bedroom apartments, and underground parking for 14 cars.

  Common areas and their approximate sizes include a recreation room and laundry room (36 m^2 combined), an office (8 m^2), a storage room (5 m^2) and a public washroom (6 m^2) on the ground floor, and an electrical room (9 m^2), a machine room (6 m^2) and a mechanical room (11 m^2) in the basement. The total area of common spaces, not including corridors and lobbies, is approximately 81 m^2.

  According to the building superintendent, all suites are occupied. The majority of occupancy is for seniors. Indoor air quality tests were conducted in three apartments: 112, 217 and 304.

- **Building Envelope:** This is a 3-storey wood frame apartment building. The exterior walls consist of 19 mm stucco finish on metal lath (or some portion with vinyl siding), building paper, 10 mm sheathing, 50 x 100 mm wood studs @ 600 o.c., 100 mm fiberglass batt insulation, 6 mil poly vapour barrier and 13 mm gypsum wall board. The wood studs cover approximately 18% of the area. The effective thermal resistance of the wall assembly was estimated to be about RSI 2.1.[1]

  The flat roof consists of 2-ply mopped bituminous membrane, 12 mm plywood sheathing, roof trusses at 600 mm o.c., 265 mm fiberglass batts, 6 mil poly and 10 mm gypsum wall board. The sloped roof consists of 225 lb/sqft asphalt shingles, 10 mm plywood sheathing, roof trusses @ 600 mm o.c., 265 mm fiberglass batt insulation, 6 mil poly and 10 mm interior gypsum wall board. The effective thermal resistance of the roof assembly was estimated to be about RSI 3.25.

  There are several sizes of windows in the building. About 20% of windows are double-glazed picture windows with thermally broken aluminum framing. The other 80% are double sliders. The field survey showed that the weatherstripping on these windows was in good acceptable

[1] The effective thermal resistance of the envelope assembly was determined using the DOE-2.1E program's material and component library.

condition. It was also reported by the superintendent that some tenants keep their windows open even during winter months.

The basement level of the building is unfinished. The below grade concrete walls are 200 mm thick and have not been insulated. The underground parking is not insulated.

- **Space Heating System:** The space heating is accomplished with electric baseboard heaters located along the perimeter of the building.

  The forced-air make-up air system is provided for the corridor and common area ventilation. The make-up air is heated using the natural gas. The heater is rated at 77 MBtu (22.5 kW). There are two fresh air risers in the building with two fans each with a capacity to provide 750 CFM (354 L/s) of air. The make-up air fan runs continuously. The heating capacity of gas heater is controlled by a supply air temperature thermostat.

- **Domestic Hot Water System:** There is a central domestic water system in the building. There are two gas-fired domestic hot water boilers each rated at 250 MBtu (73.2 kW). There are two hot water tanks. The total hot water storage tank capacity is about 574 L.

- **Ventilation Systems and Strategies:** The primary source of exhaust in the building is kitchen and bathroom fans that are turned on at the discretion of the tenants.

  The make-air system provides ventilation to corridors and common area rooms. There are two fans each rated at 472 L/s. This fan is scheduled to operate continuously. Corridor air can enter into the suites through the suite door undercut.

- **Lighting System:** The corridor and common area lighting system includes conventional fluorescent lamps. In each suite, tenants use the conventional lamps and high intensity lighting fixtures. The exterior lighting system uses conventional fixtures.

- **Appliances and Other Systems:** Laundry room is located in the basement which includes four sets of washer and dryer equipment. Each suite has four major appliances such as stoves, refrigerator, dishwasher and microwave. Most suites have one television set and a stereo system.

- **Metering:** The building is bulk metered for gas and common area electricity; tenants are billed for electricity use in the apartments.

2. AIR LEAKAGE AND VENTILATION SYSTEMS

2.1. AIR LEAKAGE TEST

The air leakage characteristics of the building envelope was determined using the whole building airtightness tests. The whole building airtightness tests were conducted using the test protocol developed by National Research Council for CMHC[2]. The airtightness test results were evaluated using the analytical procedures described in the CGSB Standard 149.10.[3]

For conducting the airtightness test, two blower doors were setup in the building. The airtightness characteristics were as follows:

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[2] CMHC 1990 **Establishing the protocols for measuring air leakage and air flow patterns in high-rise apartment buildings.** Prepared by R.J. Magee and C.Y. Shaw of IRC/NRC for CMHC, Ottawa.

[3] CGSB 1988. **CGSB Standard 149.10 (new draft - 1994) — Determination of Airtightness of Building Envelopes by the Fan Depressurization Method**, Canadian General Standards Board, Ottawa, Ontario

Table 1: Air leakage characteristics of the test building.

C, L/(s.Pa^n)	766.362	L/(sPa^n)
n	0.588	
ACH at ΔP of 50 Pa	3.45	ac/hr
ELA at ΔP 10 Pa	11,910	cm^2
Airtightness	2.84	L/sm^2 at 50 Pa
	3.60	L/sm^2 at 75 Pa

2.2. AIR CHANGE RATE TEST

The air change rate was determined in three units using the passive sampling devices (PFT) for a period of one week. Table 2 shows the normal air change rate measured during the one week period. The air change rate includes effects of both the natural air change due to the air leakage, inter zone air movement and the mechanical ventilation in the building. It should be noted that the windows in all units were closed during the testing.

Table 2: Air change rate determined using the PFT sampling.

Building	Unit	Result (ACH)
Vancouver 'MV'	112	0.47 ± 0.07
	217	0.55 ± 0.1
	304	0.62 ± 0.08

2.3. CORRIDOR MAKE-UP AIR SYSTEM

The purpose of the measurements of the corridor make-up air flows were to determine the performance of make-up air ventilation system. Table 3 shows the air flow measurements. At the time of testing, make-up air fans delivered a total of 852 L/s. The design capacity of make-up air system is about 944 L/s.

Table 3: Measurements of corridor make-up air flows.

Building	Floor	Measured Air Flow (L/s)
Vancouver 'MV'	1st	381
	2nd	291
	3rd	180

The air supply to suites from the corridor through the apartment door was found to be as follows:

Table 4: Air supplied to suites from apartment door undercut.

Building	Unit	Measured Air Flow (L/s)
Vancouver 'MV'	112	7
	217	9
	304	6

2.4. KITCHEN AND BATHROOM EXHAUST FANS

The air flow rates were measured for kitchen and bathroom exhaust fans in the test units. As shown in Table 5, the kitchen and bathroom fans significantly under performed. The fan ratings showed that the bathroom fan was designed to provide 80 L/s (160 CFM) and the kitchen fan to provide 150 L/s (300 CFM). The reason for the under performance of these fans was not investigated due to the scope and nature of the present study.

Table 5: Air flow measurements of kitchen and bathroom fans.

Building	Unit	Kitchen		Bathroom
		Flow (High) (L/s)	Flow (Low) L/s	Flow (L/s)
Vancouver 'MV'	112	141	73	41
	217*	n/a	n/a	62
	304	101	72	52

* In Unit 217, kitchen hood fan was defective.

3. INDOOR ENVIRONMENT PARAMETERS

3.1. OCCUPANT SURVEY

A questionnaire was distributed to each tenant in the building. Questions were designed to determine the opinions of tenants with regard to the performance of the building and status of the indoor air quality. The sample questionnaire, both in English and French, is provided in Appendix B. Questions pertained to:

- the performance of the building in terms of indoor air quality, odour and moisture control;
- the use of the building including the presence of pets and smokers, and time spent at home; and
- general health including identification of asthma and allergies.

The survey questionnaire was distributed to all 45 apartments. Completed survey forms were returned by 30 tenants. The response rate was about 67%.

The number of tenants occupying each suite was between 1 and 2, with an average of 1.1. There were generally very few complaints with this building. Several tenants did find the winter humidity levels too low.

3.2. INDOOR AIR TEMPERATURE

Indoor air temperatures were measured in three suites for a period of one week beginning on December 1, 1995 to December 7, 1995 using a continuous data logger. Data was collected at a 10 minutes interval.

Figure 3-1 shows a typical profile of the indoor air temperature in an occupied unit. Figure 3-2 shows the histogram of the measured temperature readings in the building. As shown, more than 80% of the time, in this unit, the indoor air temperature remained below 23 °C.

The measurements in three units can be summarized as follows:

- Mean temperatures were between 21.5 and 22.5 °C.
- The maximum temperature recorded was 25.4 °C and the minimum temperature recorded was 16.3 °C, a difference of 9.1 °C. The differences in temperature between the recorded maximum and the recorded minimum in each apartment were 7.6, 5.5 and 6.2 °C. The apartment with the highest maximum was not the apartment with the highest recorded minimum, however the apartment with the lowest recorded maximum was also the apartment with the lowest recorded minimum.

Figure 3-1: Profile of indoor air temperature in a test suite.

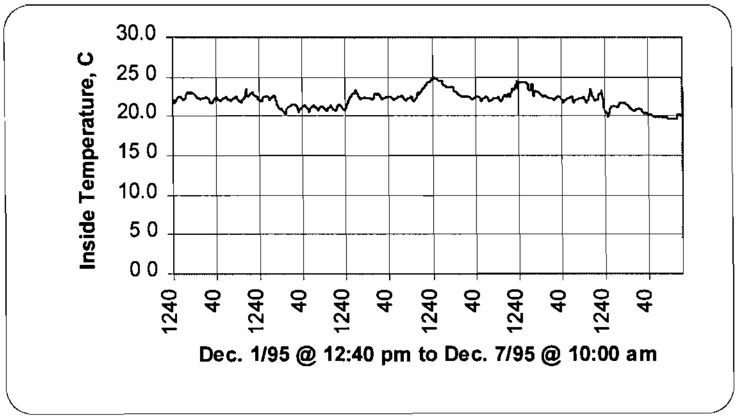
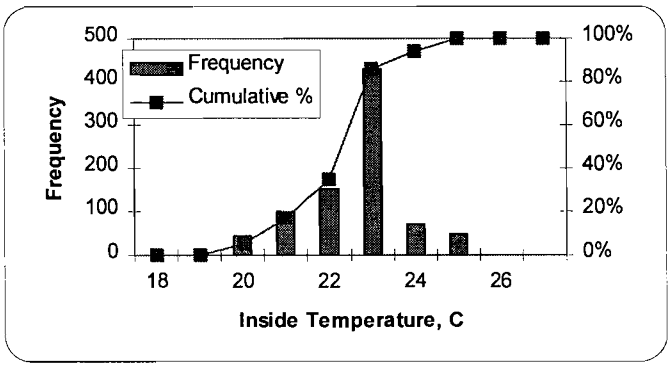


Figure 3-2: Frequency distribution of indoor air temperature in the test suite.



- Temperatures in apartment 112 were typically between 20 and 23 °C, mostly around 21 or 22 °C; daily fluctuations were typically around 3.5 °C. Temperatures in apartment 217 were mostly between 20 and 25 °C, and most of those were around 22 or 23 °C; daily fluctuations were not generally more than 2 or 3 °C. Temperatures fluctuated between highs and lows in apartment 304, rarely staying at one temperature for very long; daily temperature fluctuations were usually in the range of 4 °C.
- Temperatures were monitored at three heights in apartment 304; the highest temperatures were recorded at the ceiling and the lowest at the floor. Temperature fluctuations were much more pronounced at the ceiling than at the floor, or even mid-height.

From the above measured data, it is shown that the average temperature in the building remained at around 23 °C.

3.3. RELATIVE HUMIDITY

The relative humidity readings were taken in three suites for a period of one week beginning on December 1, 1995 to December 7, 1995 using a continuous data logger. Data was collected at a 10 minutes interval. Figure 3-3 shows a typical profile of the indoor relative humidity in an occupied unit. Figure 3-4 shows the histogram of the measured relative humidity readings in the building. As shown, more than 90% of time in this unit, the indoor RH remained within 35 to 45% range.

Figure 3-3: Profile of indoor relative humidity in a test suite.

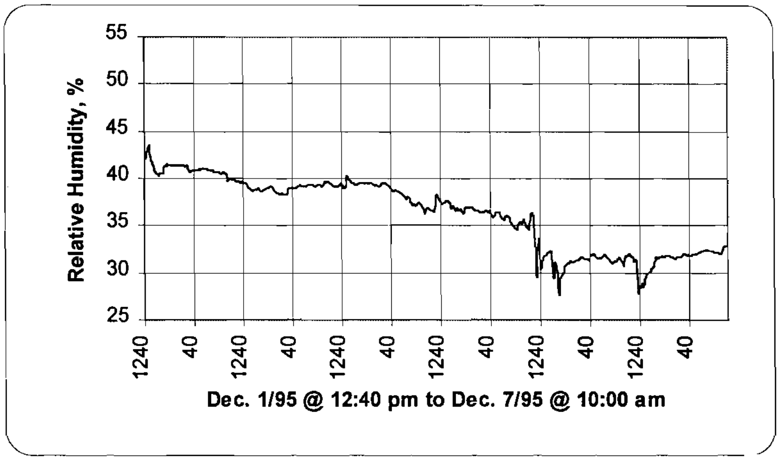
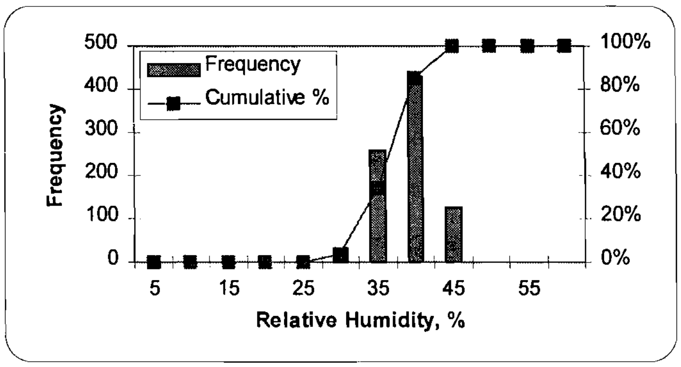


Figure 3-4: Frequency distribution of indoor relative humidity in the test suite.



The measurements in three units can be summarized as follows:

- The highest mean RH was in the lower apartment and the lowest mean RH was in the higher apartment.
- Mean RH were between 33.4 and 41.5 %.
- The maximum RH recorded was 53.4 % and the minimum was 27.5 %, a difference of 25.9 %. The differences in RH between the recorded maximum and the recorded minimum in each apartment were 18.1, 16.0 and 14.3 %. The apartment with the highest recorded maximum was also the apartment with the highest recorded minimum, however the apartment with the lowest recorded maximum was not the apartment with the lowest recorded minimum.
- RH in apartment 112 was generally between 38 and 43 %. RH was between about 37 and 42 % for the first half of the week in apartment 217, and decreased over the whole week until about the last 48 hours; daily fluctuations were not generally more than 1 or 2 %, until the last 48 hours where they were more erratic. RH decreased gradually over the monitoring period in apartment 304, starting at approximately 40 % and finishing at approximately 28 %; daily fluctuations were about 2 to 3 %.

From the above measured data, it is shown that the average relative humidity in the building ranged from about 30% to 45% with an overall average of about 40%. At the time of the monitoring, this level of relative humidity is normal for maintaining the occupant comfort.

3.4. CARBON DIOXIDE

The carbon dioxide readings were taken in three suites for a period of one week beginning on December 1, 1995 to December 7, 1995 using a continuous data logger. Data was collected at 10 minute intervals. Figure 3-5 shows a typical profile of the carbon dioxide in an occupied unit. Figure 3-6 shows the histogram of the measured carbon dioxide readings in the building. As shown, almost all time, in this test unit, the carbon dioxide levels remained below 750 ppm. The average CO_2 levels were about 600 ppm which is much lower than recommended levels of about 1,000 ppm.

CO_2 generally fluctuated between 400 and 700 in apartment 112, with daily fluctuations of about 250 ppm, but were as high as 830 ppm. CO_2 was mostly around 480 ppm, fluctuating up to approximately 775 ppm in apartment 304; daily fluctuations were about 200 or 220 ppm. Daily fluctuations in apartment 217 were approximately 400 or 450 ppm; readings typically went from high to low, with no "typical" values to note.

From the above measured data, it is shown that the average CO_2 levels in the building were significantly lower than 1,000 ppm in all units. At the time of the monitoring, these levels of carbon dioxide levels were acceptable for maintaining the occupant comfort.

Figure 3-5: Profile of carbon dioxide levels in a test suite.

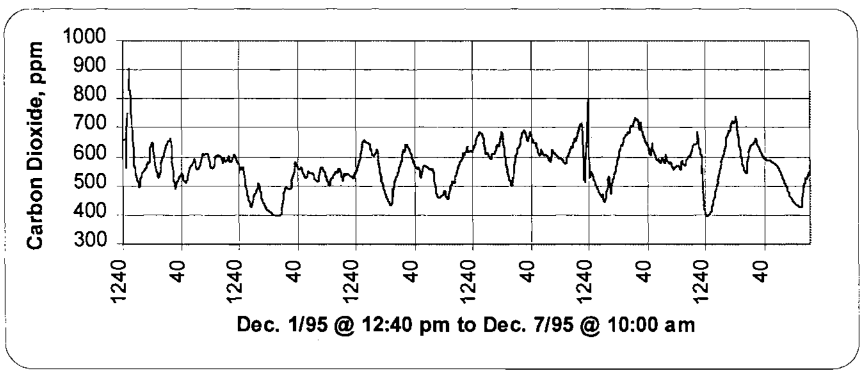
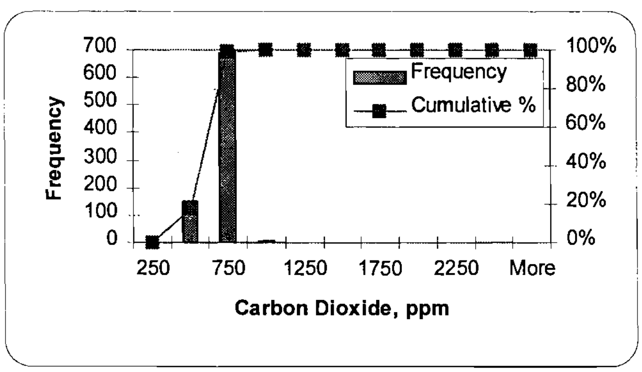


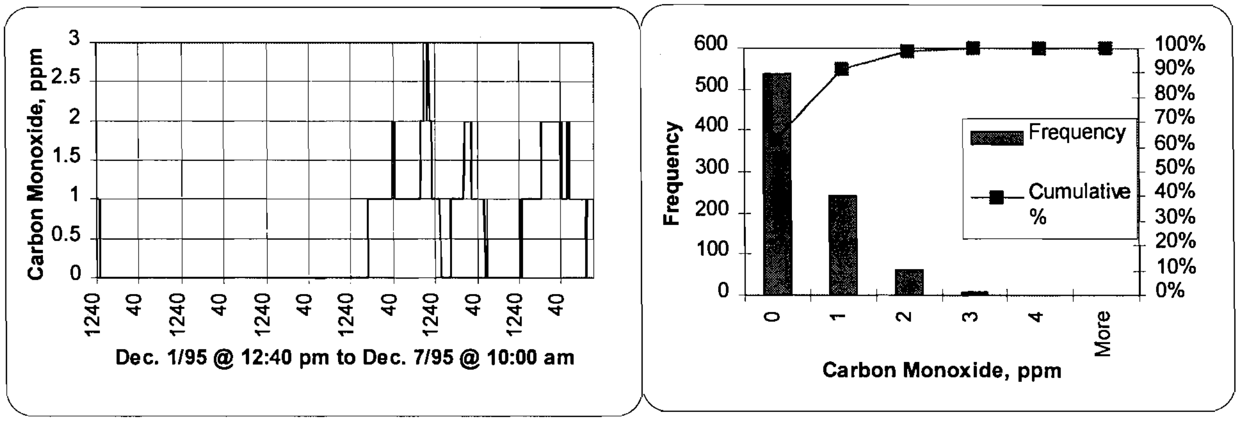
Figure 3-6: Frequency distribution of carbon dioxide levels in a test suite.



3.5. CARBON MONOXIDE

In this building, the carbon monoxide levels in the three suites ranged from negligible values to a maximum value of about 3 ppm as shown in Figure 3-7. The higher levels of carbon monoxide in this building is still significantly lower than the maximum allowable value of 11 ppm.

Figure 3-7: Profile of carbon monoxide levels in a unit.



3.6. ELECTROMAGNETIC FIELDS (EMFS)

The intensity of electromagnetic fields were measured in some suites. The electromagnetic fields were measured with and without power turned on in the living area. As shown in the following Table 6, the EMF readings were well below recommended levels of 8 milligauss in this building.

Table 6: Electromagnetic fields in suites with and without power on.

		Living Room (milligauss)		Master Bedroom (milligauss)		Kitchen (milligauss)		Bathroom (milligauss)	
Building	Unit	with	without	with	without	with	without	with	without
Vancouver 'MV'	112	0.71	0.47	0.52	0.52	0.43	0.43	0.42	0.43
	217	0.39	0.36	0.64	0.37	0.82	0.57	0.42	0.36
	304	0.34	0.33	0.33	0.35	0.46	0.31	0.29	0.30

3.7. VOLATILE ORGANIC COMPOUNDS (VOCS)

The VOCs were sampled in three apartment units for a period of one week. Table 7 shows the traces of some VOC compounds in the building. Fora a detailed analysis, unit 112 was chosen because low air changes and relatively higher levels of CO_2. The measured levels of VOCs are significantly lower than the target level of 1 mg/m^3 for acceptable indoor air quality in residences.

3.8. FORMALDEHYDE

Two AQR dosimeters were placed in 3 apartment units for a period of seven days. The formaldehyde levels were about 0.02, 0.05 and 0.025 ppm in Unit 112, 217 and 304 respectively. The formaldehyde levels were significantly lower than action level of 0.10 ppm suggested by Health Canada.

Table 7: Volatile Organic Compounds in the test building.

	Unit	Target Compound	Result (mg/m^3)
Vancouver 'MV'	112	TVOCI	0.05
	217	TVOC	0.03
	304	TVOC	0.03

3.9. LIGHTING LEVELS

Lighting levels were measured in common area and corridors. Table 8 summarizes the average levels of lighting in the building.

Table 8: Lighting levels in the common area of building.

Common Area	Lighting Level (foot candles)
Corridors	1.5
Front Lobby	6
Elevators	6
Elevator Lobbies	1.5
Stairwells	12-50
Laundry Room	50
Recreation Room	25

4. ENERGY PERFORMANCE OF THE BUILDING

The energy performance of the building was evaluated using the DOE-2.1E energy simulation program. Data input files for the energy simulation programs were created using the field survey of various components, equipment and systems, and using the architectural drawings of the building.

4.1. UTILITY BILLS

The space heating in suite is accomplished using electric baseboards. The make-up air is heated with natural gas. The domestic hot water is provided by a central hydronic boiler. The annual energy use totals were developed using the electricity and natural gas bills. Utility bills were available for the full year of 1994. Energy analysis was therefore performed for the year 1994.

4.2. ENERGY ANALYSIS RESULTS

A detailed energy analysis was undertaken to evaluate the energy performance of the building. DOE-21.E input data files were prepared and were simulated using the Vancouver weather files for the year 1994.

The hourly energy analysis showed that the annual heat losses during the heating season accounted for a total of 403.2 MWh. Heat loss components are shown in Figure 4-1. Conduction heat losses through walls accounted for 54.6 MWh (13.6%). Roof and below grade components accounted for 20.4 MWh (5.1%) and 41.1 MWh (10.2%) respectively. Heat losses through windows accounted for about 72.6 MWh (18%) annually. The mechanical ventilation in the building accounted for 78.5 MWh (19.5%). The air leakage heat losses were about 136 MWh (33.7%).

The heat gains in the building includes solar and internal gains. The internal gains are sensible heat gains due to occupancy, lighting, hot water and other energy consuming equipment. As shown in Figure 4-2, the total heat gains during the heating season were about 403.2 MWh. Solar gains accounted for 44 MWh (10.9%) of energy for offsetting the purchased energy requirements for the building. The internal gains were about 70.8 MWh or 17.5% of the total. The purchased space heating energy was about 288.4 MWh or 71.5% of the total energy requirements in the building.

The DOE-2.1E simulation for the weather year showed that the total energy requirement for the year 1994 was about 574.7 MWh. The energy use profile is shown in Figure 4-3. As shown in the figure, the lighting energy use is about 9.4% of the total. Space heating energy use accounted for 50.2% of the total energy use in the building. As shown in Table 9 and Table 10, the energy consumption profiles compared within 6% with the measured utility data for a year of utility data.

Figure 4-4 shows the energy cost balance sheet for the building. It can be seen from the balance sheet that energy use for space heating and domestic hot water accounts for more than 60% of the purchased energy costs. Energy conservation measures aimed at reducing the hot water use in the building can improve the energy efficiency. The electricity use for common area lighting and other appliances also constitute somewhat high cost expenditure.

Figure 4-1: Heat loss components.

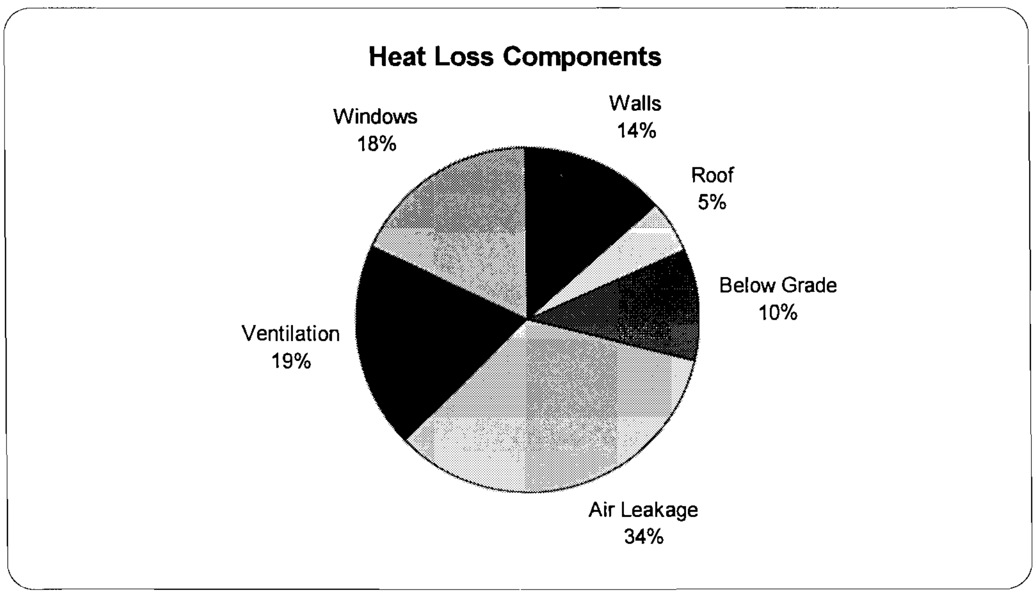


Table 9: Summary of estimates and actual use of electricity in the building.

Year	Electricity (kWh) Common Areas	Electricity (kWh) Apartments	Total Electricity (kWh)	Total Electricity DOE2.1e (kWh)
1994	90,640	157,173	247,813	268,087

Table 10: Summary of estimates and actual use of natural gas in the building.

Year	Actual Gas Use(GJ)	Estimated Gas Use DOE21.e (GJ)
1994	1,131	1,148

Figure 4-2: Components of heat gains in the building.

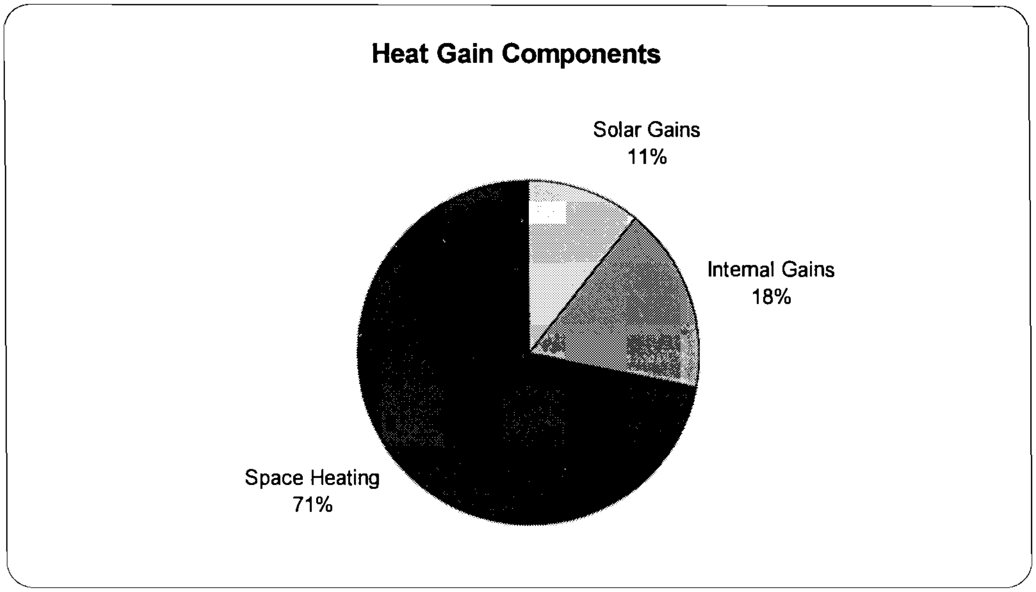


Figure 4-3: Profile of energy use in the building.

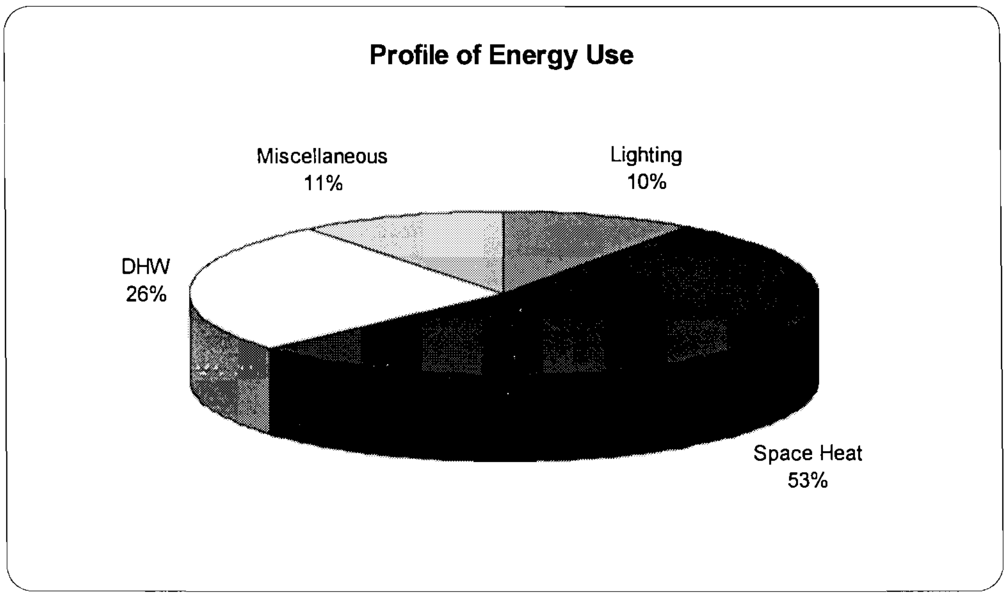


Figure 4-4: Energy cost balance sheet for the building (based on DOE-2.1E estimates).

Year 1994

Cost of Energy Supply			Cost of Energy Use		
Solar Gains	$ 1,274	5.6%	Walls, Roof and Below Grade	$ 3,359	14.8%
Internal Gains	$ 2,046	9 0%	Windows and Exterior Doors	$ 2,099	9 2%
Space Heating	$ 8,340	36 6%	Air Leakage	$ 3,933	17 3%
DHW	$ 4,071	17.9%	Ventilation	$ 2,269	10.0%
Base Use	$ 7,039	30 9%	DHW+Base Use	$ 11,110	48 8%
Estimated Energy Supply Cost	**$ 22,770**		**Estimated Cost of Energy Use**	**$ 22,770**	

5. DISCUSSION AND COMMENTS

The following comments pertain to the building performance and comparisons with appropriate required construction practices:

- The field survey showed that the building is very well kept and well maintained. The airtightness test showed that the envelope air leakage is about 3.60 L/s.m^2 at 75 Pa pressure difference. The airtightness value is significantly higher than what can be expected in buildings. This building generally satisfies the thermal characteristics of envelope components as per the 1990 BC Building Code.
- The ventilation system provides adequate fresh air flows to corridors. The corridor air leading to suites was adequate. The air leakage and opening of windows in the building during the test time kept the CO_2 levels and formaldehyde levels significantly low. It seems that there is sufficient amount of ventilation air introduced in the suites tested. Our review of the ventilation system showed that the building meets the intent of the appropriate BC Building Code for providing required natural or mechanical ventilation requirements. The actual performance monitoring showed that the ventilation systems (natural and mechanical) did perform as per the minimum requirements as per the CSA F-326.
- The annual purchased energy in the building is about 175.8 kWh/m^2 (16.3 kWh/ft^2) of the floor space. About 50% of the total annual energy is attributed to the space heating requirements and 25% of annual energy use is for domestic hot water needs. Electrical loads (lighting, appliances, fans, etc.) accounts for 25% of total energy consumption.

Appendix A-7: Vancouver 'SB' Building

Building Report

ENERGY USE AND INDOOR AIR QUALITY IN MID-RISE APARTMENT BUILDINGS

Field Investigation and Energy Analysis Report

Appendix A-7: Vancouver 'SB' Building

1. FIELD SURVEY

The subject building is a 4-storey apartment building located in Vancouver, British Columbia. The building was built in 1993 as a group/retirement home. At the time of the field survey, the building was fully occupied. As part of the project, a detailed field survey was undertaken and an inventory of energy consuming equipment and systems was prepared. The field survey included the data collection of building and systems information required for hourly energy simulation using the DOE-2.1E. The indoor environment survey was conducted using test protocols which are described in Appendix B.

The following briefly describes various building characteristics:

- **Building Layout:** The main entrance of this building faces south. The gross floor area of the building is approximately 2,705 m^2. There are 30 one-bedroom apartments on the top three storeys and a group home with four bedrooms for handicapped people on the ground floor. There is also a commercial space on the ground floor, but it is completely separate from the residential building, both in terms of access, mechanical systems and utility bills.

  Common areas and their approximate sizes include an amenity room, lounge and laundry room (98 m^2), an electrical room (8 m^2) and a mechanical room (11 m^2) on the ground floor. The total area of common spaces, not including corridors and lobbies, is approximately 116 m^2.

  According to the building superintendent, all suites are occupied. The majority of occupancy is for seniors. Indoor air quality tests were conducted in three apartments: 203, 304, and 403.

- **Building Envelope:** This is a 4-storey slab-on-grade apartment building. The exterior walls consist of 19 mm stucco finish on metal lath, building paper, 13 mm sheathing, 50 x 100 mm wood studs @ 600 o.c., 89 mm fiberglass batt insulation, 6 mil poly vapour barrier and 13 mm gypsum wall board. Some portion of wall is cladded with 190 mm concrete block. The wood studs cover approximately 14% of the area. The effective thermal resistance of the wall assembly was estimated to be about RSI 2.32.[1]

  The flat roof consists of gravel ballast, 13 mm protection board (plywood sheathing), waterproof membrane, 38X185 mm shims at 400 mm vented space, wood joists, RSI 4.9 batts, 6 mil poly and 16 mm gypsum wall board on a channel @ 200 mm o.c. The sloped roof consists of 26 ga metal cladding, 38x89 mm strapping at 600 mm o.c., vented space, RSI 4.9 batts, 6 mil poly and 16 mm gypsum wall board. The effective thermal resistance of the roof assembly was estimated to be about RSI 3.25.

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[1] The effective thermal resistance of the envelope assembly was determined using the DOE-2.1E program's material and component library.

There are several sizes of windows in the building. About 30% of windows are double-glazed picture windows and remaining single hung. The field survey showed that the weatherstripping on theses windows was in good condition.

- **Space Heating System:** The space heating is accomplished with electric baseboard heaters located along the perimeter of the building on the upper floors (2nd to 4th floor). There is a gas hydronic heating system with a radiant slab on the ground floor where a four-bedroom group home is located.

  The forced-air make-up air system is provided for the corridor and common area ventilation. The make-up air is heated using the natural gas heaters. There are two hot water boilers each rated at 108 MBtu (31.6 kW) which serve hot water as well as make-up air heating.. There is a single fresh air riser in the building with a fan of 1,500 CFM (708 L/s) of air. The make-up air fan runs continuously. The heating capacity of gas boiler is controlled by indoor/outdoor temperature difference.

  For ground floor radiant heating system, a 100 MBtu (29.3 kW) boiler provides the hot water. The metering for this boiler use is separated for

- **Domestic Hot Water System:** There is a central domestic water system in the building. There are two hot water boilers which use the natural gas and each one is rated at 108 MBtu (31.6 kW) as described in the space heating. There is a hot water tank with a 286 L capacity. Note that the two boilers serve both DHW and the make-up air heating.

- **Ventilation Systems and Strategies:** The primary source of exhaust in the building is kitchen and bathroom fans that are turned on at the discretion of the tenants.

  The make-air system provides ventilation to corridors and common area rooms. There is a central fan rated at 708. This fan is scheduled to operate continuously. Corridor air can enter in to suites through the door undercut and door.

- **Lighting System:** The corridor and common area lighting system includes conventional fluorescent lamps. In each suite, tenants use the conventional lamps and high intensity lighting fixtures. The exterior lighting system uses conventional fixtures.

- **Appliances and Other Systems:** Laundry room is located in the basement which includes four sets of washer and dryer equipment. Each suite has four major appliances such as stoves, refrigerator, dishwasher and microwave. Most suites have one television set and a stereo system.

- **Metering:** The building is bulk metered for gas and common area electricity; tenants are billed for electricity use in the apartments.

2. AIR LEAKAGE AND VENTILATION SYSTEMS

2.1. AIR LEAKAGE TEST

The air leakage characteristics of the building envelope was determined using the whole building airtightness tests. The whole building airtightness tests were conducted using the test protocol

developed by National Research Council for CMHC[2]. The airtightness test results were evaluated using the analytical procedures described in the CGSB Standard 149.10.[3]

For conducting the airtightness test, two blower doors were setup in the building. The airtightness characteristics were as follows:

Table 1: Air leakage characteristics of the test building.

C, L/(s.Pa^n)	593.220	L/(sPa^n)
n	0.62	
ACH at ΔP of 50 Pa	3.58	ac/hr
ELA at ΔP 10 Pa	9,934	cm^2
Airtightness	2.78	L/sm^2 at 50 Pa
	3.58	L/sm^2 at 75 Pa

2.2. AIR CHANGE RATE TEST

The air change rate was determined in one unit using the passive sampling devices (PFT) for a period of one week. Table 2 shows the normal air change rate measured during the one week period. The air change rate includes effects of both the natural air change due to the air leakage, inter zone air movement and the mechanical ventilation in the building. It should be noted that the windows in all units were closed during the testing.

Table 2: Air change rate determined using the PFT sampling.

Building	Unit	Result (ACH)
Vancouver 'SB'	203	0.75 ± 0.11

2.3. CORRIDOR MAKE-UP AIR SYSTEM

The purpose of the measurements of the corridor make-up air flows were to determine the performance of make-up air ventilation system. Table 3 shows the air flow measurements. At the time of testing, make-up air fans delivered a total of 490 L/s. The design capacity of make-up air system is about 708 L/s.

Table 3: Measurements of corridor make-up air flows.

Building	Floor	Measured Air Flow (L/s)
Vancouver 'SB'	1st	35
	2nd	174
	3rd	70
	4th	111

The air supply to suites from the corridor through the apartment door was found to be as follows:

Table 4: Air supplied to suites from apartment door undercut.

Building	Unit	Measured Air Flow (L/s)
Vancouver 'SB'	203	5
	304	5
	403	0

[2] CMHC 1990. **Establishing the protocols for measuring air leakage and air flow patterns in high-rise apartment buildings.** Prepared by R.J Magee and C Y Shaw of IRC/NRC for CMHC, Ottawa.

[3] CGSB 1988 **CGSB Standard 149.10 (new draft - 1994) — Determination of Airtightness of Building Envelopes by the Fan Depressurization Method**, Canadian General Standards Board, Ottawa, Ontario.

2.4. KITCHEN AND BATHROOM EXHAUST FANS

The air flow rates were measured for kitchen and bathroom exhaust fans in the test units. As shown in Table 5, the kitchen and bathroom fans performed very well. The fan ratings showed that the bathroom fan was designed to provide 100 L/s (200 CFM) and the kitchen fan to provide 100 L/s (200 CFM). The reason for the under performance of these fans was not investigated due to the scope and nature of the present study.

Table 5: Air flow measurements of kitchen and bathroom fans.

Building	Unit	Kitchen		Bathroom
		Flow (High) (L/s)	Flow (Low) L/s	Flow (L/s)
Vancouver 'SB'	203	86	53	88
	304	86	68	76
	403	89	65	80

3. INDOOR ENVIRONMENT PARAMETERS

3.1. OCCUPANT SURVEY

A questionnaire was distributed to each tenant in the building. Questions were designed to determine the opinions of tenants with regard to the performance of the building and status of the indoor air quality. The sample questionnaire, both in English and French, is provided in Appendix B. Questions pertained to:

- the performance of the building in terms of indoor air quality, odour and moisture control;
- the use of the building including the presence of pets and smokers, and time spent at home; and
- general health including identification of asthma and allergies.

The survey questionnaire was distributed to all 30 apartments. Completed survey forms were returned by 28 tenants. The response rate was about 93%.

The number of tenants occupying each suite was between 1 and 2, with an average of 1.1. Most people were satisfied with the general air quality, although 50% were not happy with the temperature in the building; many felt that it was inconsistent (sometimes too hot, sometimes too cold). 36% of the respondents felt that the air was either too stale or stuffy, with one tenant saying that it was drafty. Most of these tenants also felt that there were disagreeable odours in the building. 36% of respondents felt that the building was responsible for their health problems. Except for one tenant, there was no correlation between tenants who felt that the humidity level was too high in the winter (11%) and those who had condensation on the windows in the winter (21%); 25% of respondents felt that the relative humidity was too low in the winter. For summer months, 11% of respondents felt that the humidity was too high while 21% felt that it was too low. There was no apparent correlation between those who found it too high in the summer and those who found it too high in the winter.

3.2. INDOOR AIR TEMPERATURE

Indoor air temperatures were measured in three suites for a period of one week beginning on December 8, 1995 to December 15, 1995 using a continuous data logger. Data was collected at a 10 minutes interval.

Figure 3-1 shows a typical profile of the indoor air temperature in an occupied unit. Figure 3-2 shows the histogram of the measured temperature readings in the building. As shown, more than 90% of the time, in this unit, the indoor air temperature remained below 22 °C.

The highest mean temperature was in the middle apartment and the lowest mean temperature was in the lowest apartment.

- Mean temperatures ranged between 20.0 and 24.7 °C.
- The maximum temperature recorded was 26.9 °C and the minimum temperature recorded was 15.9 °C, a difference of 11 °C. The differences in temperature between the recorded maximum and the recorded minimum in each apartment were 8.1, 5.6 and 4.6 °C. The apartment with the highest maximum was also the apartment with the highest recorded minimum.
- Temperatures were mostly between 20 and 22 °C in apartment 203. Daily fluctuations were generally approximately 2 °C, but were as high as 8 °C in the first day of monitoring and 4.5 °C on another occasion. Daily fluctuations in apartment 304 were approximately 3 °C, at mid-height - more at the ceiling and less at the floor level. Temperatures were, for the most part, between 24 and 27 °C. Temperatures in apartment 403 were generally about 20 or 22 °C. Daily fluctuations were generally about 1 °C.
- In apartment 304, temperatures were monitored at three heights in the room: ceiling-, mid- and floor-height. There is a noticeable temperature gradient, with those measured at the ceiling approximately 2 °C higher than those at the floor.

From the above measured data, it is shown that the average temperature in the building remained at around 22 °C. The outdoor conditions did affect the indoor temperatures.

3.3. RELATIVE HUMIDITY

The relative humidity readings were taken in three suites for a period of one week beginning on December 8, 1995 to December 15, 1995 using a continuous data logger. Data was collected at a 10 minutes interval. Figure 3-3 shows a typical profile of the indoor relative humidity in an occupied unit. Figure 3-4 shows the histogram of the measured relative humidity readings in the building. As shown, more than 90% of time in this unit, the indoor RH remained within 25 to 45% range.

Figure 3-1: Profile of indoor air temperature in a test suite.

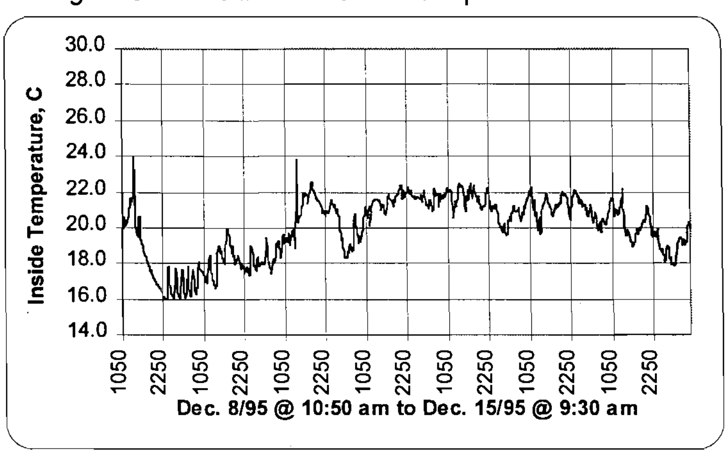


Figure 3-2: Frequency distribution of indoor air temperature in the test suite.

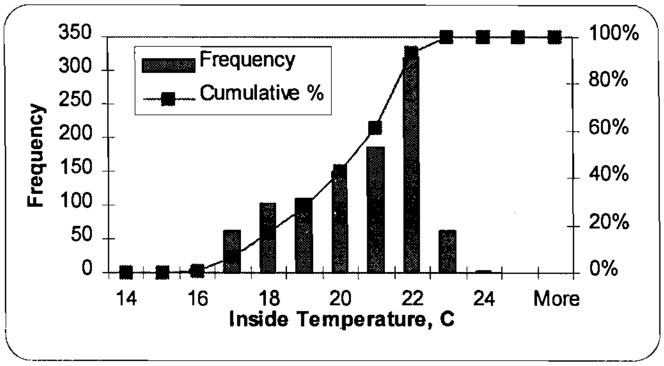


Figure 3-3: Profile of indoor relative humidity in a test suite.

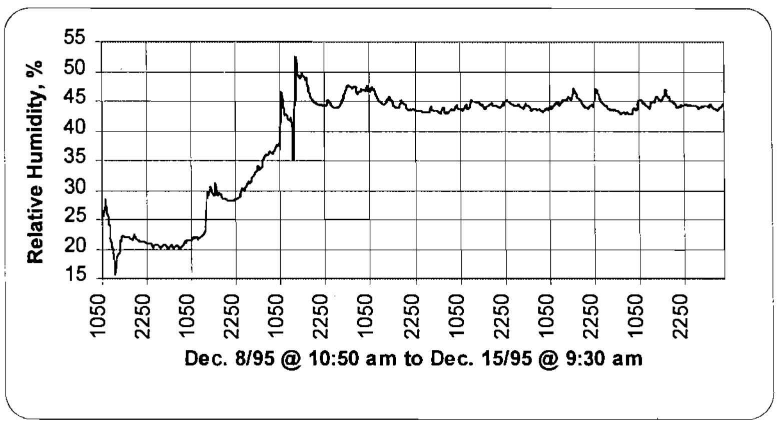
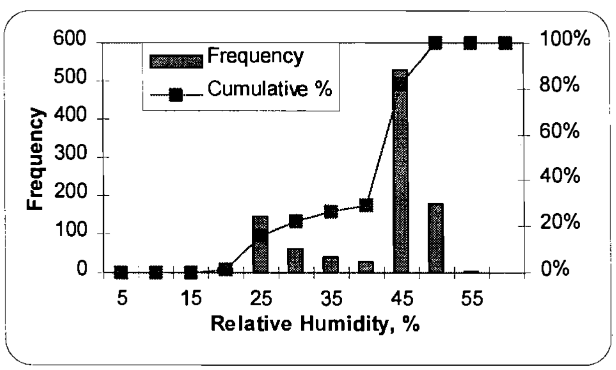


Figure 3-4: Frequency distribution of indoor relative humidity in the test suite.



The measurements in three units can be summarized as follows:

- The highest mean RH was in the highest apartment and the lowest mean RH was the middle apartment.
- Mean RH varied between 38.0 and 40.8 %.
- The maximum RH recorded was 52.6% and the minimum was 15.4%, a difference of 37.2%. The differences in RH between the recorded maximum and the recorded minimum in each apartment are 37.2, 21.5 and 18.8%. The apartment with the highest recorded maximum was the apartment with the lowest recorded minimum.

- RH was, for the most part, around 45%. Daily fluctuations were usually about 2%, but were as high as 24%. RH is apartment 304 was mostly between 35 and 45 %; daily fluctuations were usually about 10%. Daily fluctuations are generally between 3 and 5 °C.

From the above measured data, it is shown that the average relative humidity in the building ranged from about 30% to 45% with an overall average of about 40%. At the time of the monitoring, this level of relative humidity is normal for maintaining the occupant comfort.

3.4. CARBON DIOXIDE

The carbon dioxide readings were taken in three suites for a period of one week beginning on December 8, 1995 to December 15, 1995 using a continuous data logger. Data was collected at a 10 minutes interval. Figure 3-5 shows a typical profile of the carbon dioxide in an occupied unit. Figure 3-6 shows the histogram of the measured carbon dioxide readings in the building. As shown, almost all time, in this test unit, the carbon dioxide levels remained below 750 ppm. The average CO_2 levels were about 650 ppm which is much lower than recommended levels of about 1,000 ppm.

Daily fluctuations were usually about 300 ppm in apartment 203 with readings generally between 350 and 600 ppm; daily fluctuations were about 350 ppm in apartment 304 with readings generally between 500 and 900 ppm. Daily fluctuations were usually between 250 and 300 ppm in apartment 403, but were as high as 500 ppm, with readings generally between 600 and 800 ppm.

From the above measured data, it is shown that the average CO_2 levels in the building were significantly lower than 1,000 ppm in all units. At the time of the monitoring, these levels of carbon dioxide levels were acceptable for maintaining the occupant comfort.

3.5. CARBON MONOXIDE

In this building, the carbon monoxide levels in the three suites ranged from negligible values to a maximum value of about 3 ppm as shown in Figure 3-7. The negative values shown in the graph were due to mal-functioning of the monitor. Instantaneous measurements were taken to verify the continuous measurements. The higher levels of carbon monoxide in this building is still significantly lower than the maximum allowable value of 11 ppm.

Figure 3-5: Profile of carbon dioxide levels in a test suite.

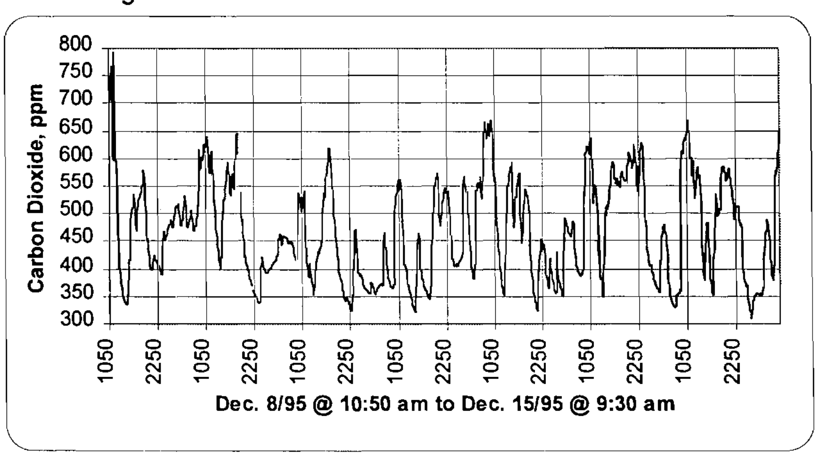


Figure 3-6: Frequency distribution of carbon dioxide levels in a test suite.

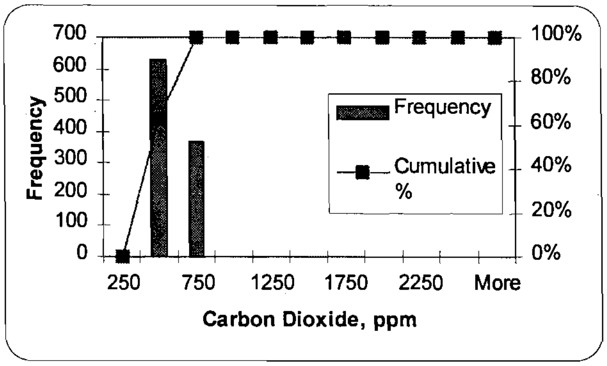
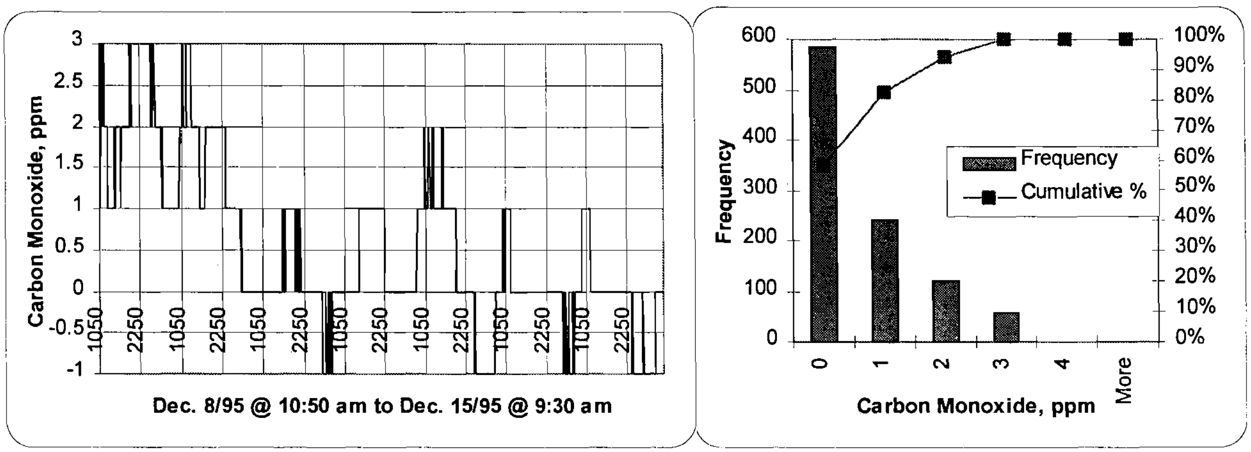


Figure 3-7: Profile of carbon monoxide levels in a unit.



3.6. ELECTROMAGNETIC FIELDS (EMFS)

The intensity of electromagnetic fields were measured in some suites. The electromagnetic fields were measured with and without power turned on in the living area. As shown in the following Table 6, the EMF readings were well below recommended levels of 8 milligauss in this building.

Table 6: Electromagnetic fields in suites with and without power on.

		Living Room (milligauss)		Master Bedroom (milligauss)		Kitchen (milligauss)		Bathroom (milligauss)	
Building	Unit	with	without	with	without	with	without	with	without
Vancouver 'SB'	203	1.44	1.41	1.28	1.21	1.19	1.30	1.57	1.41
	304	1.05	1.06	0.88	0.81	0.76	0.74	0.47	0.58
	403	1.12	1.07	1.02	1.03	1.22	0.83	2.19	0.94

3.7. VOLATILE ORGANIC COMPOUNDS (VOCS)

The VOCs were sampled in three apartment units for a period of one week. Table 7 shows the traces of some VOC compounds in the building. For detailed VOC analysis, unit 304 was chosen because low air changes and relatively higher levels of CO_2. The measured levels of VOCs are significantly lower than the target level of 1 mg/m^3 for acceptable indoor air quality in residences.

Table 7: Volatile Organic Compounds in the test building.

	Unit	Target Compound	Result (mg/m^3)
Vancouver 'SB'	203	all	0.04
	304	TVOC	0.12
	403	TVOC	0.06

3.8. FORMALDEHYDE

Two AQR dosimeters were placed in 3 apartment units for a period of seven days. The formaldehyde levels were about 0.035, 0.03 and 0.04 ppm in Unit 203, 304 and 403 respectively. The formaldehyde levels were significantly lower than action level of 0.10 ppm suggested by Health Canada.

3.9. LIGHTING LEVELS

Lighting levels were measured in common area and corridors. Table 8 summarizes the average levels of lighting in the building. In corridors, lighting levels were low.

Table 8: Lighting levels in the common area of building.

Common Area	Lighting Level (foot candles)
Corridors	3
Front Lobby	12-25
Elevators	25
Elevator Lobbies	12
Stairwells	12
Laundry Room	50
Recreation Room	12

4. ENERGY PERFORMANCE OF THE BUILDING

The energy performance of the building was evaluated using the DOE-2.1E energy simulation program. Data input files for the energy simulation programs were created using the field survey of various components, equipment and systems, and using the architectural drawings of the building.

4.1. UTILITY BILLS

The space heating in suite is accomplished using electric baseboard heating system The make-up air is heated hydronically with natural gas. The domestic hot water is provided by a central hydronic boiler. The building is bulk metered for electricity, natural gas and water consumption. The annual energy use totals were developed using the electricity and natural gas bills. Utility bills were available for the full year of 1994. Energy analysis was therefore performed for the year 1994.

4.2. ENERGY ANALYSIS RESULTS

A detailed energy analysis was undertaken to evaluate the energy performance of the building. DOE-21.E input data files were prepared and were simulated using the Vancouver weather files for the year 1994.

The hourly energy analysis showed that the annual heat losses during the heating season accounted for a total of 224.5 MWh. Heat loss components are shown in Figure 4-1. Conduction heat losses through walls accounted for 38.1 MWh (17%). Roof and below grade components accounted for 11.7 MWh (5.2%) and 2.1 MWh (0.9%) respectively. Heat losses through windows accounted for about 62.7 MWh (28%) annually. The mechanical ventilation in the building accounted for 46.7 MWh (20.8%). The air leakage heat losses were about 63.2 MWh (28.2%).

The heat gains in the building includes solar and internal gains. The internal gains are sensible heat gains due to occupancy, lighting, hot water and other energy consuming equipment. As shown in Figure 4-2, the total heat gains during the heating season were about 224.6 MWh. Solar gains accounted for 24.2 MWh (10.8%) of energy for offsetting the purchased energy requirements for the building. The internal gains were about 60.4 MWh or 26.9% of the total. The purchased space heating energy was about 140 MWh or 62.3% of the total energy requirements in the building.

The DOE-2.1E simulation for the weather year showed that the total energy requirement for the year 1994 was about 397.4 MWh. The energy use profile is shown in Figure 4-3. As shown in the figure, the lighting energy use is about 14.4% of the total. Space heating energy use accounted for 35.2% of the total energy use in the building. As shown in Table 9 and Table 10, the energy consumption profiles compared within 1% with the measured utility data for a year of utility data.

Figure 4-4 shows the energy cost balance sheet for the building. It can be seen from the balance sheet that energy use for space heating and domestic hot water accounts for more than 64% of the purchased energy costs. Energy conservation measures aimed at reducing the hot water use in the building can improve the energy efficiency.

Figure 4-1: Heat loss components.

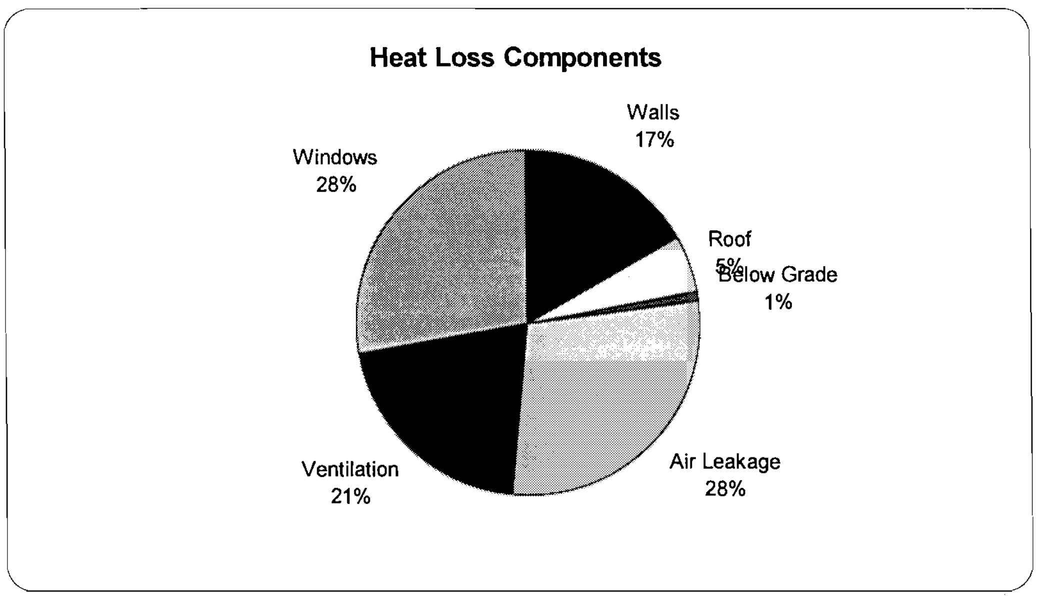


Table 9: Summary of estimates and actual use of electricity in the building.

Year	Electricity (kWh) Common Areas	Electricity (kWh) Apartments	Total Electricity (kWh)	Total Electricity DOE2.1e (kWh)
1994	64,560	142,040	206,600	196,075

Table 10: Summary of estimates and actual use of natural gas in the building.

Year	Actual Gas Use(GJ)	Estimated Gas Use DOE21.e (GJ)
1994	678	709.3

Figure 4-2: Components of heat gains in the building.

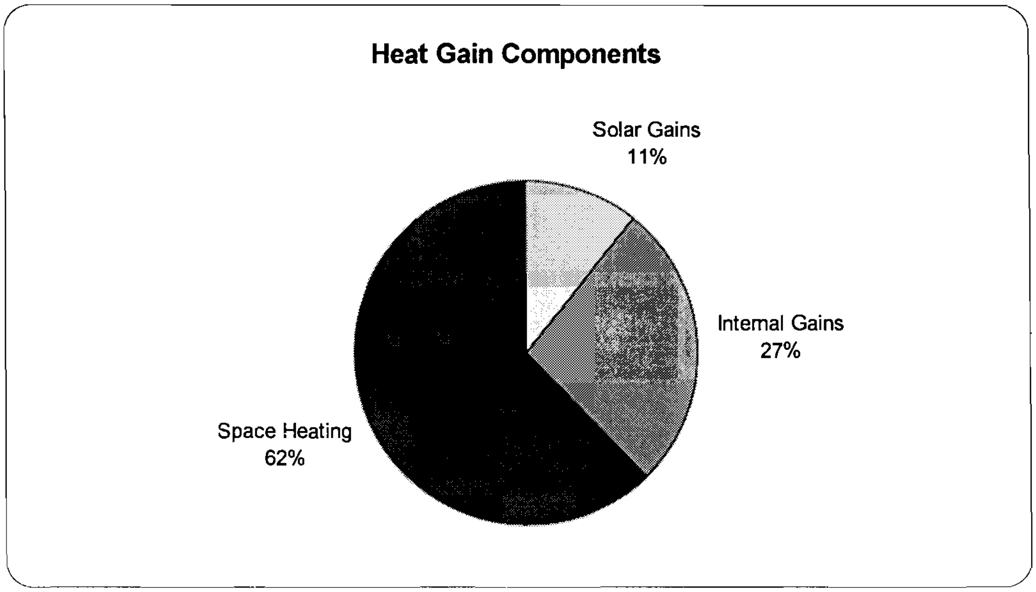


Figure 4-3: Profile of energy use in the building.

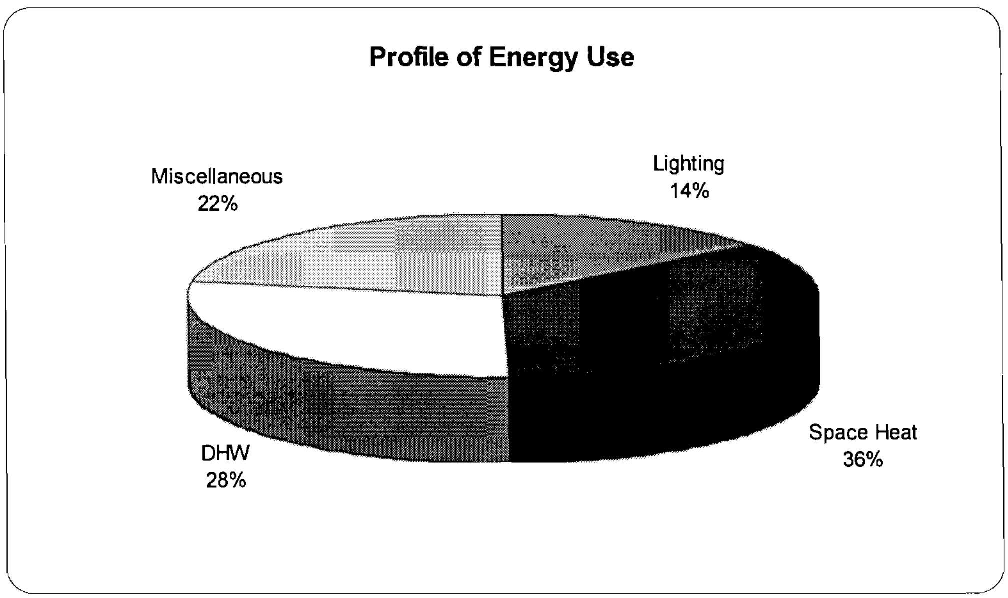


Figure 4-4: Energy cost balance sheet for the building (based on DOE-2.1E estimates).

Year 1994

Cost of Energy Supply			Cost of Energy Use		
Solar Gains	$ 702	3.7%	Walls, Roof and Below Grade	$ 1,508	7.9%
Internal Gains	$ 1,752	9.2%	Windows and Exterior Doors	$ 1,820	9.6%
Space Heating	$ 4,061	21.4%	Air Leakage	$ 1,835	9.7%
DHW	$ 2,056	10.8%	Ventilation	$ 1,354	7.1%
Base Use	$ 10,427	54.9%	DHW+Base Use	$ 12,482	65.7%
Estimated Energy Supply Cost	**$ 18,999**		**Estimated Cost of Energy Use**	**$ 18,999**	

5. DISCUSSION AND COMMENTS

The following comments pertain to the building performance and comparisons with appropriate required construction practices:

- The field survey showed that the building is very well kept and well maintained. The airtightness test showed that the envelope air leakage is about 3.58 $L/s.m^2$ at 75 Pa pressure difference. The airtightness value is significantly higher than what can be expected in buildings with air barrier systems. This building generally satisfies the thermal characteristics of envelope components as per the 1990 BC Building Code.
- The ventilation system provides adequate fresh air flows to corridors. The corridor air leading to suites was adequate in some suites while almost negligible in other. The air leakage and opening of windows in the building during the test time kept the CO_2 levels and formaldehyde levels significantly low. It seems that there is just sufficient amount of ventilation air is introduced in various suites. Our review of the ventilation system showed that the building design meets the intent of the appropriate Code for providing required natural or mechanical ventilation requirements. The actual performance monitoring showed that the ventilation systems (natural and mechanical) did perform as per the minimum requirements as per the CSA F-326.
- The annual purchased energy in the building is about 146 kWh/m^2 (13.6 kWh/ft^2) of the floor space. About 35.4% of the total annual energy is attributed to the space heating requirements and 28.4% of annual energy use is for domestic hot water needs. Electrical loads (lighting, appliances, fans, etc.) accounts for 36% of total energy consumption.

Appendix A-8: Vancouver 'W' Building

Building Report

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ENERGY USE AND INDOOR AIR QUALITY IN MID-RISE APARTMENT BUILDINGS

Field Investigation and Energy Analysis Report

Appendix A-8: Vancouver 'W' Building

1. FIELD SURVEY

The subject building is a 4-storey apartment building located in Vancouver, British Columbia. The building was built in 1993 as a co-operative building for needy women (seniors) in Vancouver. At the time of the field survey, the building was fully occupied. As part of the project, a detailed field survey was undertaken and an inventory of energy consuming equipment and systems was prepared. The field survey included the data collection of building and systems information required for hourly energy simulation using the DOE-2.1E. The indoor environment survey was conducted using test protocols which are described in Appendix B.

The following briefly describes various building characteristics:

- **Building Layout:** The main entrance of this building faces north. The gross floor area of the building is approximately 2,519 m^2 (residential space only). There are 36 one-bedroom apartments on the top three storeys. The ground floor accommodates commercial space for retail shops. The commercial floor is completely separate from the residential building, both in terms of access, mechanical systems and utility bills. There is an underground parking for 18 cars for residents and 9 spaces for commercial or service vehicles, as well as space for 54 bicycles. The IAQ and energy evaluation do not consider the commercial space in the building.

  Common areas and their approximate sizes include an office and multipurpose work area (21 m^2) on the second floor, a lounge (21 m^2) on the third floor, and a lounge (19 m^2) on the fourth floor. The total above-grade common areas, not including corridors and lobbies, is approximately 61 m^2.

  According to the building superintendent, all suites are occupied. The majority of occupancy is for seniors. Indoor air quality tests were conducted in three apartments: 203, 306, and 403.

- **Building Envelope:** This is a 4-storey wood frame apartment building. The exterior walls consist of 19 mm stucco finish on metal lath, building paper, 13 mm sheathing, 50x150 mm wood studs @ 600 o.c., RSI 3.52 (R-20) fiberglass batt insulation, 6 mil poly vapour barrier and 13 mm gypsum wall board. Some portion of wall is cladded with 200 mm cast in place concrete block, 12 mm air space, 50x100 mm wood studs, RSI 2.1 (R-12) batts, 6 mil poly, 13 mm gypsum wall boards. The wood studs cover approximately 14% of the area. The effective thermal resistance of the wall assembly was estimated to be about RSI 2.32.[1]

  The built-up roof on wood joist which consists of 2 ply modified bituminous membrane (exposed), 10 mm wood sheathing, 50x250 mm roof joists, vented roof space, RSI 4.9 (R-28) batt insulation, 6 mil poly and 16 mm gypsum wall board. The effective thermal resistance of the roof assembly was estimated to be about RSI 3.25.

[1] The effective thermal resistance of the envelope assembly was determined using the DOE-2 1E program's material and component library

There are several sizes of windows in the building. About 34% of windows are double-glazed picture windows and remaining single hung. The field survey showed that the weatherstripping on theses windows was in good acceptable condition.

- **Space Heating System:** The space heating is accomplished with a central hydronic system with a central boiler and perimeter baseboard radiators. The main heating fuel is natural gas for space heating, domestic hot water and make-up air heating. There are two boilers with one of 312 MBtu (91.3 kW) and other 631 MBtu (184.8 kW). These boilers serve the commercial floors also. Boilers are controlled by indoor/outdoor temperature controller. These boilers are used for space heating and make-up air heating.

  The forced-air make-up air system is provided for the corridor and common area ventilation. There are two fresh air risers in the building with two fans (2300 and 2700 CFM) providing a total capacity of 2,361 L/s. The make-up air fan runs continuously.

  The primary source of exhaust in the building is kitchen and bathroom fans that are turned on at the discretion of the tenants.

- **Domestic Hot Water System:** There is a central domestic water system in the building. There is one natural gas fired domestic hot water boiler rated at 300 MBtu (87.9 kW). There is a hot water storage tank with a 344 L capacity. Note that the two boilers serve both DHW and the make-up air heating.

- **Ventilation Systems and Strategies:** The primary source of exhaust in the building is kitchen and bathroom fans that are turned on at the discretion of the tenants.

  The make-air system provides ventilation to corridors and common area rooms. There are two make-up air fans with a total capacity of 2,361 L/s. These fans are scheduled to operate continuously. Corridor air can enter in to suites through the door undercut and door.

  There is a 300 CFM supply and 300 CFM exhaust fan in the underground parking garage which operates continuously.

- **Lighting System:** The corridor and common area lighting system includes conventional fluorescent lamps. In each suite, tenants use the conventional lamps and high intensity lighting fixtures. The exterior lighting system uses conventional fixtures.

- **Appliances and Other Systems:** Laundry room is located in the basement which includes four sets of washer and dryer equipment. Each suite has four major appliances such as stoves, refrigerator, dishwasher and microwave.

- **Metering:** The building is bulk metered for gas and common area electricity; tenants are billed for electricity use in the apartments.

2. AIR LEAKAGE AND VENTILATION SYSTEMS

2.1. AIR LEAKAGE TEST

The air leakage characteristics of the building envelope was determined using the whole building airtightness tests. The whole building airtightness tests were conducted using the test protocol developed by National Research Council for CMHC. The airtightness test results were evaluated using the analytical procedures described in the CGSB Standard 149.10.[2]

[2] CGSB 1988. **CGSB Standard 149.10 (new draft - 1994) — Determination of Airtightness of Building Envelopes by the Fan Depressurization Method**, Canadian General Standards Board, Ottawa, Ontario.

For conducting the airtightness test, two blower doors were setup in the building. The airtightness characteristics were as follows:

Table 1: Air leakage characteristics of the test building.

C, L/(s.Pa^n)	421.348	L/(sPa^n)
n	0.67	
ACH at ΔP of 50 Pa	3.35	ac/hr
ELA at ΔP 10 Pa	7,845	cm^2
Airtightness	2.67	L/sm^2 at 50 Pa
	3.49	L/sm^2 at 75 Pa

2.2. AIR CHANGE RATE TEST

The air change rate was determined in three units using the passive sampling devices (PFT) for a period of one week. Table 2 shows the normal air change rate measured during the one week period. The air change rate includes effects of both the natural air change due to the air leakage, inter zone air movement and the mechanical ventilation in the building. It should be noted that the windows in all units were closed during the testing.

Table 2: Air change rate determined using the PFT sampling.

Building	Unit	Result (ACH)
Vancouver 'W'	203	1.00 ± 0.15
	306	0.91 ± 0.1
	403	0.72 ± 0.12

2.3. CORRIDOR MAKE-UP AIR SYSTEM

The purpose of the measurements of the corridor make-up air flows were to determine the performance of make-up air ventilation system. Table 3 shows the air flow measurements. At the time of testing, make-up air fans delivered a total of 2,323 L/s. The design capacity of make-up air system is about 2,361 L/s. The garage lobby has a 300 CFM supply fan.

Table 3: Measurements of corridor make-up air flows.

Building	Floor	Measured Air Flow (L/s)
Vancouver 'W'	1st	618
	2nd	586
	3rd	611
	4th	508
	Garage lobby	118

The air supply to suites from the corridor through the apartment door was found to be as follows:

Table 4: Air supplied to suites from apartment door undercut.

Building	Unit	Measured Air Flow (L/s)
Vancouver 'W'	203	1
	306	13
	403	0

2.4. KITCHEN AND BATHROOM EXHAUST FANS

The air flow rates were measured for kitchen and bathroom exhaust fans in the test units. As shown in Table 5, the kitchen and bathroom fans performed near to their rated capacity. The fan ratings showed that the bathroom fan was designed to provide 80 L/s (160 CFM) and the kitchen fan to provide 100 L/s (200 CFM). The reason for the under performance of these fans was not investigated due to the scope and nature of the present study.

Table 5: Air flow measurements of kitchen and bathroom fans.

Building	Unit	Kitchen Flow (High) (L/s)	Kitchen Flow (Low) L/s	Bathroom Flow (L/s)
Vancouver 'W'	203	62	56	78
	306	72	52	71
	403	73	61	88

3. INDOOR ENVIRONMENT PARAMETERS

3.1. OCCUPANT SURVEY

A questionnaire was distributed to each tenant in the building. Questions were designed to determine the opinions of tenants with regard to the performance of the building and status of the indoor air quality. The sample questionnaire, both in English and French, is provided in Appendix B. Questions pertained to:

- the performance of the building in terms of indoor air quality, odour and moisture control;
- the use of the building including the presence of pets and smokers, and time spent at home; and
- general health including identification of asthma and allergies.

The survey questionnaire was distributed to all 36 apartments. Completed survey forms were returned by 34 tenants. The response rate was about 94%.

The number of tenants occupying each suite was 1 in all cases. Almost half the tenants are dissatisfied with the air quality in the building. 44% of the tenants found the general air quality to be stuffy or stale, and two tenants found it too drafty. There were approximately the same number of complaints regarding the temperature (either too hot or inconsistent) and relative humidity, with no obvious correlation between these incidences. There were almost the same number of complaints regarding health problems that were attributed to the building. Once again, there is no discernible correlation to other complaints. There was a significant number of tenants (44%) who found odour to be a problem; some of these complaints were about a fast food restaurant in the adjoining building, others about cooking, car odours and cigarette smoke. Far fewer tenants complained of window condensation in the winter (15%) and mold (0%).

3.2. INDOOR AIR TEMPERATURE

Indoor air temperatures were measured in three suites for a period of one week beginning on November 23, 1995 to November 30, 1995 using a continuous data logger. Data was collected at a 10 minutes interval.

Figure 3-1 shows a typical profile of the indoor air temperature in an occupied unit. Figure 3-2 shows the histogram of the measured temperature readings in the building. As shown, more than 90% of the time, in this unit, the indoor air temperature remained below 25 °C.

The highest mean temperature was in the middle apartment and the lowest mean temperature was in the lowest apartment.

- The highest mean temperature was in the upper apartment and the other two apartments had the same mean temperature.
- Mean temperatures were between 23.9 and 24.2 °C.
- The maximum recorded temperature was 25.8 °C and the minimum recorded temperature was 22.3 °C, a difference of 3.5 °C. The differences in temperature between the recorded maximum and the recorded minimum in each apartment were 3.3, 2.9 and 2.0 °C. The highest maximum temperature was found in two apartments, and they also had the highest two recorded minimum temperatures.
- Temperatures at mid-height were generally between 24 and 25 °C in apartment 203; daily fluctuations were usually 1 or 2 °C. Temperatures were fairly constant in apartment 306 at approximately 23 or 24 °C; daily fluctuations were approximately 0.5 to 1 °C. Temperatures in apartment 403 were fairly constant around 24 °C; daily fluctuations were in the neighborhood of 0.25 °C.
- Temperatures were monitored at three heights in apartment 203; the highest temperatures were recorded at the ceiling and the lowest at the floor. Temperature fluctuations were much more pronounced at the floor than at the ceiling, or mid-height.

From the above measured data, it is shown that the average temperature in the building remained at around 24 °C. The outdoor conditions did affect the indoor temperatures.

3.3. RELATIVE HUMIDITY

The relative humidity readings were taken in three suites for a period of one week beginning on November 23, 1995 to November 30, 1995 using a continuous data logger. Data was collected at a 10 minutes interval. Figure 3-3 shows a typical profile of the indoor relative humidity in an occupied unit. Figure 3-4 shows the histogram of the measured relative humidity readings in the building. As shown, more than 90% of time in this unit, the indoor RH remained within 45 to 50% range.

Figure 3-1: Profile of indoor air temperature in a test suite.

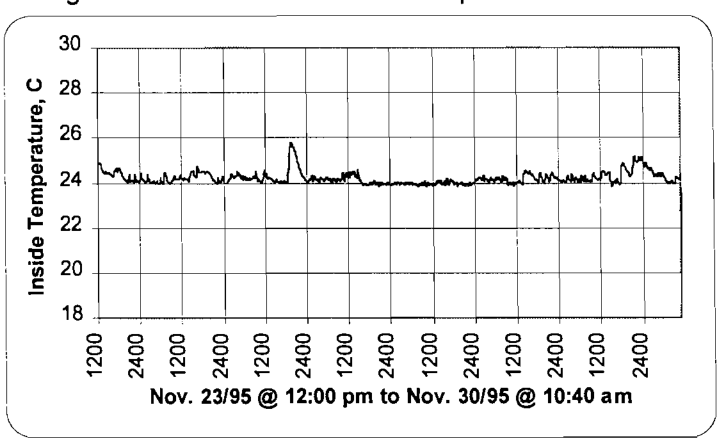


Figure 3-2: Frequency distribution of indoor air temperature in the test suite.

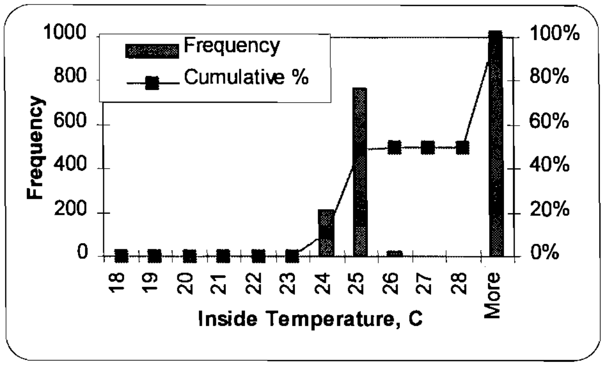


Figure 3-3: Profile of indoor relative humidity in a test suite.

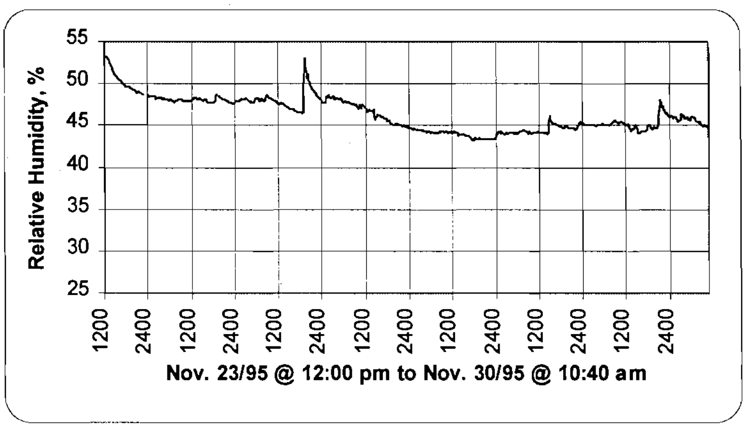
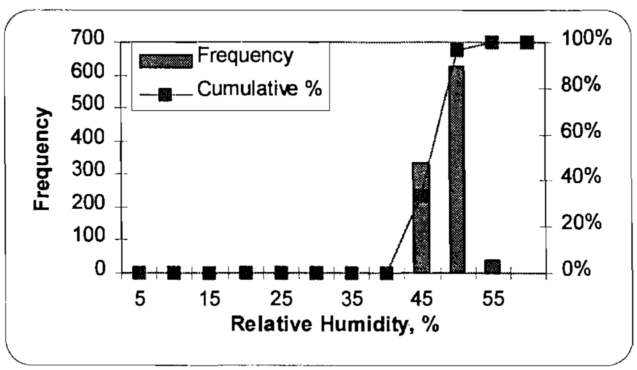


Figure 3-4: Frequency distribution of indoor relative humidity in the test suite.



The measurements in three units can be summarized as follows:

- The highest mean RH was in the upper apartment and the lowest mean RH was in the middle apartment.
- Mean RH were between 24.5 and 46.3 %.
- The maximum recorded RH was 53.3 % and the minimum was 31.3 %, a difference of 22.0 %. The differences in RH were between the recorded maximum and the recorded minimum in each apartment were 13.3, 12.3 and 10.1 %. The apartment with the highest recorded maximum was also the apartment with the highest recorded minimum. Likewise, the

apartment with the lowest recorded maximum was also the apartment with the lowest recorded minimum.

- RH was generally between 37 and 39 % in apartment 203. RH was generally between 32 and 36 % in apartment 306. RH was fairly constant in apartment 403, although it decreased gradually over the week of monitoring from approximately 50 to around 45 %.

From the above measured data, it is shown that the average relative humidity in the building ranged from about 30% to 55% with an overall average of about 40%. At the time of the monitoring, this level of relative humidity is normal for maintaining the occupant comfort.

3.4. CARBON DIOXIDE

The carbon dioxide readings were taken in three suites for a period of one week beginning on November 23, 1995 to November 30, 1995 using a continuous data logger. Data was collected at 10 minute interval. Figure 3-5 shows a typical profile of the carbon dioxide in an occupied unit. Figure 3-6 shows the histogram of the measured carbon dioxide readings in the building. As shown, almost all time, in this test unit, the carbon dioxide levels remained around 750 to 1000 ppm. The average CO_2 levels were about 800 ppm which is lower than recommended levels of about 1,000 ppm. It should be noted that for about 20% of the time, the CO_2 levels were about 1,250 ppm.

Daily fluctuations in apartment 203 were generally 200 to 250 ppm; CO_2 was usually in the range of 400 or 500 ppm. CO_2 in apartment 306 was generally between 300 and 450 ppm; daily fluctuations were generally around 100 or 125 ppm. Daily fluctuations in apartment 403 were around 600 ppm; CO_2 varied greatly and went from highs to lows.

From the above measured data, it is shown that the average CO_2 levels in the building were in some units were near to 1,000 ppm. At the time of the monitoring, these levels of carbon dioxide levels were somewhat acceptable for maintaining the occupant comfort.

3.5. CARBON MONOXIDE

In this building, the carbon monoxide levels in the three suites ranged from negligible values to a maximum value of about 2 ppm as shown in Figure 3-7. The higher levels of carbon monoxide in this building is still significantly lower than the maximum allowable value of 11 ppm.

Figure 3-5: Profile of carbon dioxide levels in a test suite.

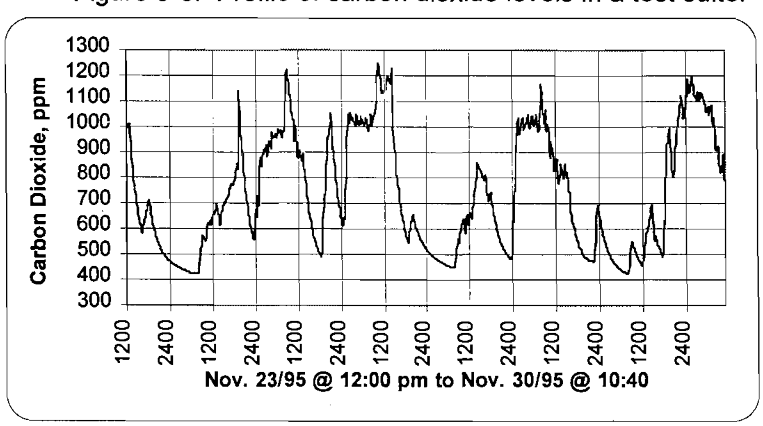


Figure 3-6: Frequency distribution of carbon dioxide levels in a test suite.

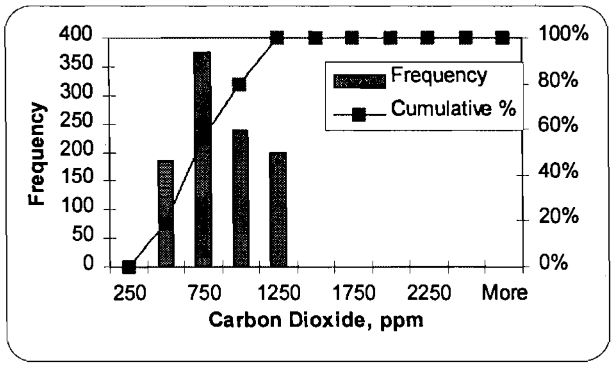
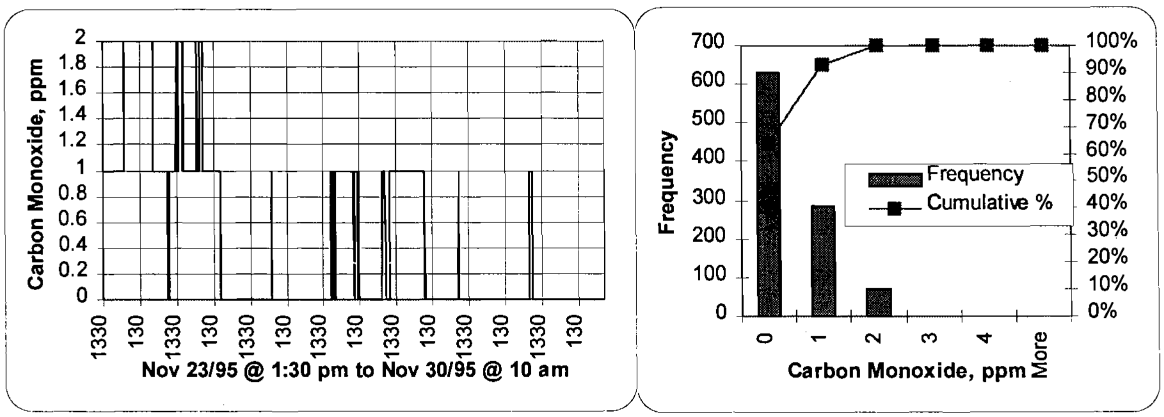


Figure 3-7: Profile of carbon monoxide levels in a unit.



3.6. ELECTROMAGNETIC FIELDS (EMFS)

The intensity of electromagnetic fields was measured in some suites. The electromagnetic fields were measured with and without power turned on in the living area. As shown in the following Table 6, the EMF readings were well below recommended levels of 8 milligauss in this building.

Table 6: Electromagnetic fields in suites with and without power on.

		Living Room (milligauss)		Master Bedroom (milligauss)		Kitchen (milligauss)		Bathroom (milligauss)	
Building	Unit	with	without	with	without	with	without	with	without
Vancouver 'W'	203	0.45	0.33	0.66	0.50	0.38	0.22	0.29	0.21
	306	0.43	0.32	0.52	0.52	0.82	0.45	0.45	0.40
	403	0.24	0.25	0.37	0.29	1.11	0.40	0.35	0.24

3.7. VOLATILE ORGANIC COMPOUNDS (VOCS)

The VOCs were sampled in three apartment units for a period of one week. Table 7 shows the traces of some VOC compounds in the building. For a detailed VOC analysis, unit 203 was chosen because low air changes and relatively higher levels of CO_2. The measured levels of VOCs are significantly lower than the target level of 1 mg/m^3 for acceptable indoor air quality in residences.

Table 7: Volatile Organic Compounds in the test building.

	Unit	Target Compound	Result (mg/m^3)
Vancouver 'W'	203	all	0.04
	306	TVOC	0.02
	403	TVOC	0.03

3.8. FORMALDEHYDE

Two AQR dosimeters were placed in 3 apartment units for a period of seven days. The formaldehyde levels were about 0.05, 0.04 and 0.04 ppm in Unit 203, 306 and 403 respectively. The formaldehyde levels were significantly lower than action level of 0.10 ppm suggested by Health Canada.

3.9. LIGHTING LEVELS

Lighting levels were measured in common area and corridors. Table 8 summarizes the average levels of lighting in the building. Minimum requirement is for 5 foot-candles.

Table 8: Lighting levels in the common area of building.

Common Area	Lighting Level (foot candles)
Corridors	6-12
Front Lobby	3
Elevators	25
Elevator Lobbies	3
Stairwells	3-25
Laundry Room	50
Recreation Room	6

4. ENERGY PERFORMANCE OF THE BUILDING

The energy performance of the building was evaluated using the DOE-2.1E energy simulation program. Data input files for the energy simulation programs were created using the field survey of various components, equipment and systems, and using the architectural drawings of the building.

4.1. UTILITY BILLS

The space heating in suite is accomplished using central hydronic heating system The make-up air is heated with natural gas. The domestic hot water is provided by a central hydronic boiler. The annual energy use totals were developed using the electricity and natural gas bills. Utility bills were available for the full year of 1994. Energy analysis was therefore performed for the year 1994.

4.2. ENERGY ANALYSIS RESULTS

A detailed energy analysis was undertaken to evaluate the energy performance of the building. DOE-21.E input data files were prepared and were simulated using the Vancouver weather files for the year 1994.

The hourly energy analysis showed that the annual heat losses during the heating season accounted for a total of 221.9 MWh. Heat loss components are shown in Figure 4-1. Conduction heat losses through walls accounted for 23.5 MWh (10.6%). Roof and below grade components accounted for

18.4 MWh (8.3%) and 12.4 MWh (5.6%) respectively. Heat losses through windows accounted for about 81.1 MWh (37%) annually. The mechanical ventilation in the building accounted for 47.3 MWh (21.3%). The air leakage heat losses were about 39.1 MWh (17.6%).

The heat gains in the building includes solar and internal gains. The internal gains are sensible heat gains due to occupancy, lighting, hot water and other energy consuming equipment. As shown in Figure 4-2, the total heat gains during the heating season were about 221.9 MWh. Solar gains accounted for 15.9 MWh (7.2%) of energy for offsetting the purchased energy requirements for the building. The internal gains were about 61.2 MWh or 27.6% of the total. The purchased space heating energy was about 144.7 MWh or 65.2% of the total energy requirements in the building.

The DOE-2.1E simulation for the weather year showed that the total energy requirement for the year 1994 was about 498.6 MWh. The energy use profile is shown in Figure 4-3. As shown in the figure, the lighting energy use is about 20.6% of the total. Space heating energy use accounted for 29% of the total energy use in the building. As shown in Table 9 and Table 10, the energy consumption profiles compared within 3% with the measured utility data for a year of utility data.

Figure 4-4 shows the energy cost balance sheet for the building. It can be seen from the balance sheet that energy use for space heating and domestic hot water accounts for more than 55% of the purchased energy costs. Energy conservation measures aimed at reducing the hot water use in the building can improve the energy efficiency.

Figure 4-1: Heat loss components.

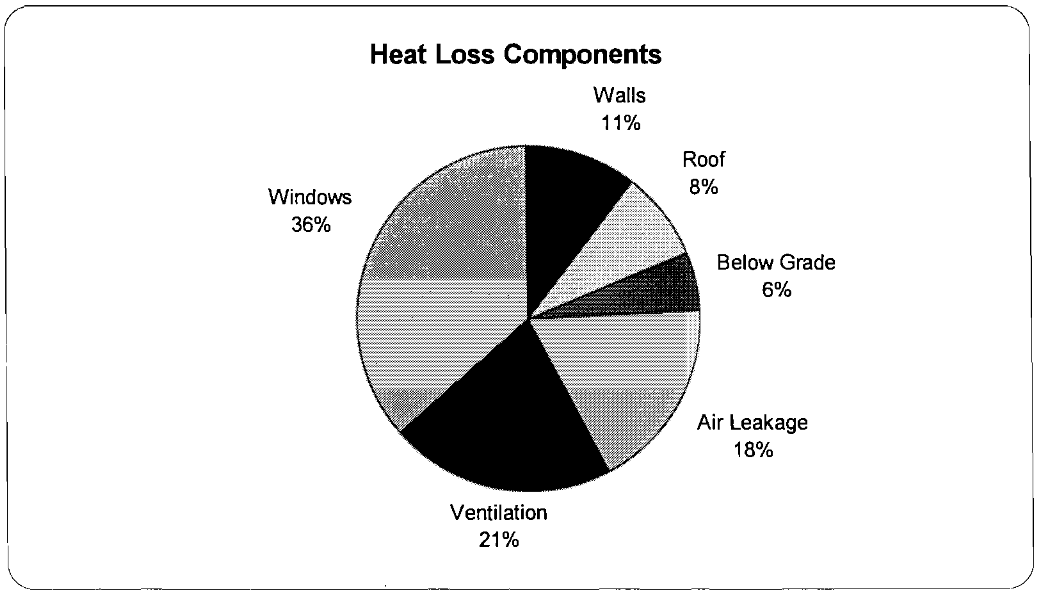


Table 9: Summary of estimates and actual use of electricity in the building.

Year	Electricity (kWh) Common Areas	Electricity (kWh) Apartments	Total Electricity (kWh)	Total Electricity DOE2.1e (kWh)
1994	157,956	72705	230,661	226,769

Table 10: Summary of estimates and actual use of natural gas in the building.

Year	Actual Gas Use(GJ)	Estimated Gas Use DOE21.e (GJ)
1994	1,305	1,279

Figure 4-2: Components of heat gains in the building.

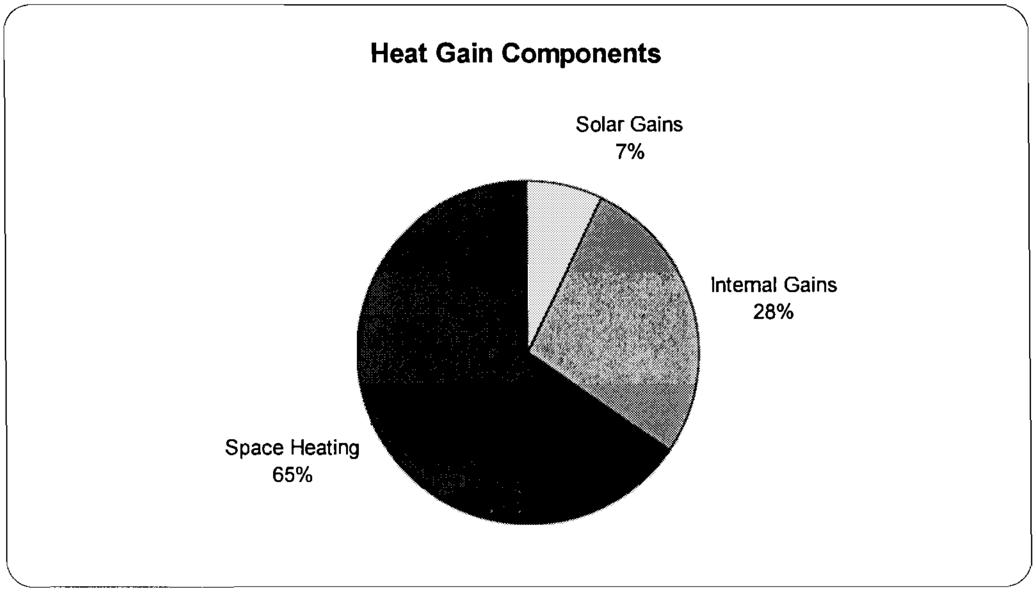


Figure 4-3: Profile of energy use in the building.

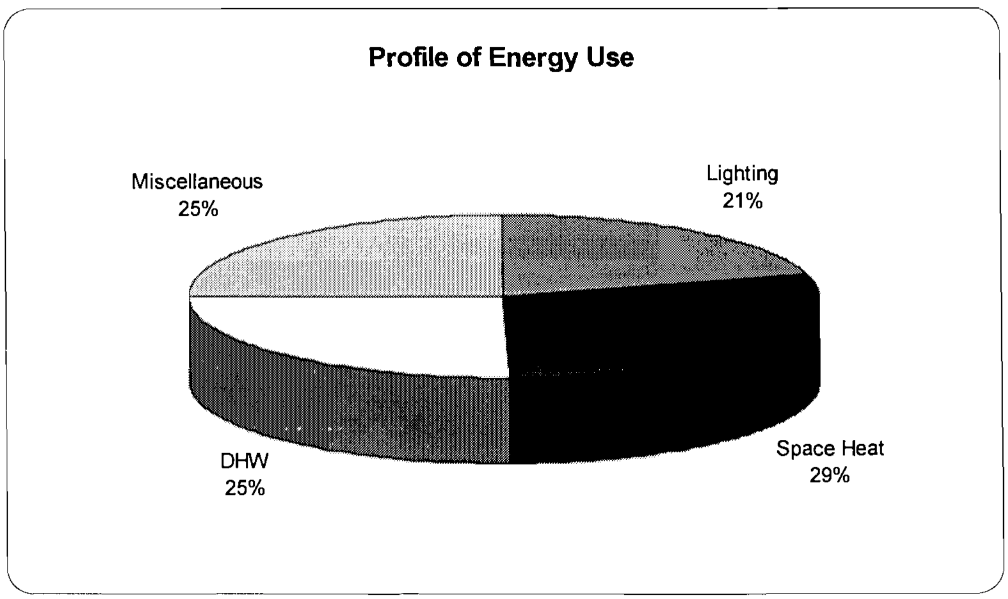


Figure 4-4: Energy cost balance sheet for the building (based on DOE-2.1E estimates).

Year 1994

Cost of Energy Supply			Cost of Energy Use		
Solar Gains	$ 285	1.4%	Walls, Roof and Below Grade	$ 969	4 7%
Internal Gains	$ 1,093	5 3%	Windows and Exterior Doors	$ 1,449	7.1%
Space Heating	$ 2,584	12 6%	Air Leakage	$ 699	3.4%
DHW	$ 2,270	11.1%	Ventilation	$ 845	4 1%
Base Use	$ 14,309	69 7%	DHW+Base Use	$ 16,579	80 7%
Estimated Energy Supply Cost	**$ 20,541**		**Estimated Cost of Energy Use**	**$ 20,541**	

5. DISCUSSION AND COMMENTS

The following comments pertain to the building performance and comparisons with appropriate required construction practices:

- The field survey showed that the building is generally looked after well. The airtightness test showed that the envelope air leakage is about 3.49 L/s.m^2 at 75 Pa pressure difference. The airtightness value is significantly higher than what can be expected in buildings with air barrier systems. The wall corners, roof/wall joint, window and wall joints, and balcony door frame and wall joints seem to be the cause of the poor airtightness. This building generally satisfies the thermal characteristics of envelope components as per the 1990 BC Building Code.
- The ventilation system provides adequate fresh air flows to corridors. The corridor air leading to suites was negligible. The air leakage and opening of windows in the building during the test time kept the CO_2 levels and formaldehyde levels low in some units but these parameters were high in some units. It seems that there is not sufficient amount of ventilation air introduced in some suites. Our review of the ventilation system showed that the building meets the intent of the appropriate Code for providing required natural or mechanical ventilation requirements. The actual performance monitoring showed that the ventilation systems (natural and mechanical) did not perform as per the minimum requirements as per the CSA F-326.
- The annual purchased energy in the building is about 199.5 kWh/m^2 (18.6 kWh/ft^2) of the floor space. About 28.8% of the total annual energy is attributed to the space heating requirements and 25.3% of annual energy use is for domestic hot water needs. Electrical loads (lighting, appliances, fans, etc.) accounts for 46% of total energy consumption.

Protocol for the Field Survey of IAQ & Energy in Mid-Rise Multi-Unit Residential Buildings

Appendix B

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Appendix B: Protocol for IAQ Investigations

PROTOCOL FOR THE FIELD SURVEY OF IAQ & ENERGY IN MID-RISE MULTI-UNIT RESIDENTIAL BUILDINGS

1. INTRODUCTION

This document defines the procedures for performing an energy and indoor air quality audit of a mid-rise residential building in accordance with the requirements of CMHC project No. 6766-6, "*Field Investigation of Energy Usage and the Indoor Environment of Mid-Rise Multi-Unit Residential Buildings*".

The scope of the audit work is limited to the following field activities:

1) Conduct a survey of building occupants and maintenance staff for the identification of energy and air quality related issues. A tenant questionnaire is distributed and used to determine which suites are suitable for detailed IAQ testing.

2) Conduct the following IAQ measurements in selected suites:

   – Temperature, relative humidity, CO and CO_2 data logging for a one week period
   – Formaldehyde sampling for a one week period (average concentration)
   – Volatile Organic Compounds sampling for a one week period (TVOC in two suites, GC/MS speciated in mid-height suite)
   – Air velocity and temperature distributions
   – Ventilation rate (volumetric flow rate of outside air into a suite)
   – Electro Magnetic Field strength (instantaneous readings)
   – Average common area lighting levels (instantaneous readings)
   – Visual inspection for fungi, mould and mildew

3) Conduct a blower door test to assess the airtightness of the building envelope.

4) Obtain information on building physical and thermal characteristics, occupancy, internal loads and operational schedules for the purpose of creating an energy simulation model of the building. Verify that the information provided on the building drawings is correct. Obtain utility billing data (3 years) and weather data (to match the year(s) of billing data) for the purpose of calibrating the building simulation model.

2. GENERAL APPROACH

The auditors will require at least two visits to each building in order to complete all of the field procedures.

One visit is required to gather physical information about the building, install and initiate the IAQ sampling and data logging, and obtain information required to conduct the blower-door and ventilation tests on a subsequent visit. This visit must be scheduled to occur in the late fall or winter when the building is in a "closed" condition.

Another visit will be required to retrieve the IAQ samplers and test equipment, conduct the blower door and ventilation tests, and collect the information required to do the energy analysis. Since the blower door test will flush-out the building pollutants and adversely affect the IAQ results, the blower door test must be carried out after[1] the completion of the indoor air quality tests.

Three visits will be required if the blower door test cannot be scheduled for the day when the IAQ equipment will be picked up.

2.1 *Preparing for the Audit*

The planning of the field tests for each building should proceed as follows:

- ❑ If possible, obtain as-built drawings (architectural, mechanical and electrical) of the building prior to the first visit. Familiarization with the building layout and construction details will reduce field legwork and can help to identify errors or omissions in the drawings.
- ❑ Obtain the energy bills for the building. Some buildings will be bulk metered while others will be individually suite metered. Utility data for individually metered suites is easier to obtain from the utility company (with appropriate authority) than the individual tenants.
- ❑ Request that the building superintendent distribute tenant questionnaires to each unit. Ask for responses within a week or two.
- ❑ When the questionnaires have been returned, and suitable units have been chosen from the survey results, inform the building owner and superintendent of the three units that have been selected. Make appointments with the building superintendent for two visits to the building (one week apart, if possible). Provide full details regarding IAQ, blower-door and ventilation tests to the building owners and their staff. In most cases, occupants require a 24-hour or 48-hour notice for access to their units. The following guidelines should be followed in selecting three apartments per building:
  - Select one suite located at the ground floor level preferably facing the major traffic. Preferably, it should be a corner unit of larger dimension.
  - Select one suite on the top floor preferably on the same orientation as the ground floor unit.
  - Select one suite located on a middle floor preferably having apartments on either side (middle unit).
  - Note the following points:
    - The test apartments should be representative of the majority of the units in the building.
    - All test apartments should have a normal level of occupancy (for example, one-bedroom with at least two persons, two-bedrooms with at least 3 to 4 persons, etc.). Either low or high occupancy in the apartment will affect the IAQ results. Ensure that test apartments have constant occupancy during the IAQ test period.
    - Avoid apartments with pets.
    - If possible, select one unit in the building with smoker(s).
    - Make sure that the test apartments have not been freshly painted, furnished with new heavy upholstery, recently carpeted and/or fumigated.

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[1] The blower door test could also be done in advance of the IAQ tests as long as there is sufficient time for the building to return to its normal air quality state before the IAQ tests are performed.

2.2 CONDUCTING THE AUDIT

Once the availability of test apartments is confirmed, the first visit to the building should be carried out by the team leader. The following tasks should be accomplished:

- ❑ If drawings were not provided prior to the first visit, make arrangements to obtain them. Become familiar with the building and make appropriate site sketches and take photographs. Record the photographs in the photo-log sheet provided with the assessment forms.
- ❑ Install the IAQ test equipment and samplers in accordance with the appropriate test specifications. Record appropriate information on the assessment forms.
- ❑ Estimate the number of depressurization fans necessary and determine suitable locations for these fans. The number of fans necessary can be estimated using the following formula:

  No. fans = 4V / 60(2500)

  where: 4 is the assumed average number of air changes per hour at 50 Pa for post 1990 mid-rise multi-unit residential buildings

  V is the volume of the building measured in ft^3

  60 is the conversion factor for hours to minutes

  2500 is the average blower door fan capacity (ft^3/min.)
- ❑ The building's heated volume and envelope area will be determined in general accordance with CGSB 149.10 Standard "Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method". A sketch of the building will be made to show the fan locations.
- ❑ Inform the building superintendent about the need for accessibility to building areas and apartments for the next round of tests. Schedule dates for the second visit.

During the second visit, the team should consist of at least two persons in order to carry out the blower door test. The following tasks are required during the second visit:

- ❑ Complete all active IAQ tests and collect instrumentation.
- ❑ Measure ventilation supply air flow rate (for central corridor distribution systems, at the supply fan(s) and at the corridor diffusers; for individual suite ventilation, at the diffuser).
- ❑ Setup and carry out the blower door test.
- ❑ Collect any information required for the energy analysis that was not collected in the first visit.

Note that this is only a guideline for the order of work and may be changed to meet with alternate schedules. For example, the blower door test and energy audit may be done at any time as long as it does not affect the IAQ testing.

3. Indoor Air Quality Audit Procedures

The following sections describe the indoor air quality audit procedures and the forms to be used in the field.

3.1 *IAQ On-Site Surveys*

The air quality assessment survey forms in CMHC's publication *"Indoor Air Quality Test Protocol for High-rise Residential Buildings"* have been modified and re-worded as necessary to reflect the conditions commonly found in mid-rise buildings. The survey characterizes the building common areas, mechanical systems and HVAC operation, and individual apartments. The survey forms used are attached at the end of this report, in Appendix A.

3.2 *Indoor Air Quality Test Specifications*

The main purpose of this indoor air quality assessment is to describe the interior environment of mid-rise multi-unit residential buildings at the time of the test. The complete IAQ field protocol includes the following tests:

Parameter	Type of Measurement
Carbon Dioxide	Continuous for one week
Carbon Monoxide	Continuous for one week
Formaldehyde	Average over a period of week
Volatile Organic Compounds	Average over a period of week
Air Temperature	Continuous for one week
Unit Air Temperature Distribution	Instantaneous
Unit Air Velocity Profiles	Instantaneous
Relative Humidity	Continuous for one week
Ventilation Rates	Instantaneous
Electro Magnetic Fields (EMF)	Instantaneous
Common Area Lighting Levels	Instantaneous
Biological (moulds, fungus)	Visual inspection

The following sections layout the specifications and application criteria for these IAQ tests.

3.2.1 Carbon Dioxide

Specifications:

Type of Measurement	Continuous data recording
Permissible exposure limits[2]	Health Canada - 3500 PPM ASHRAE Std. 62-1989 - 1000 PPM Ontario Ministry of Labour - 1000 PPM
Criteria for measurements	Measurement in most frequently occupied areas: one continuous recording per suite. - spot check all bedrooms and living areas - record hours of ventilation system operation - locate sensing device in the center of the room and at least a meter away from the operable windows - locate sensing device about 0.5 to 1 meter above the floor level - locate sensing device 0.5 meter away from corners
Duration of measurement	Five to seven days
Sample size	A minimum of three suites per building
Indoor locations	Master bedroom or living area Ground, middle and top floors
Baseline measurement	Outdoor concentration
Type of equipment	CO_2, T & RH Continuous data logger. Model YES-203
Range and accuracy	CO_2: 0-5000 PPM (0-2000 PPM LCD display); ±2% full range (± 100 PPM)
Reporting	Full data plot during test period - extract maximum, minimum and average levels.

Notes:

The CO_2 levels will be checked using the hand-held electronic meters during the deployment and retrieval of data loggers for verification purposes.

The tenants will be informed about the sensitivity of the CO_2 datalogger to their presence. It is important that the unit be placed where it will not attract attention. The tenants will be asked to maintain a simple occupancy log for the duration of the measurement.

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[2] Survey of about 21,000 units in Ontario (multi-unit residential) show that CO_2 levels typically vary from 700 to 1300 PPM. CMHC's fifty home survey found that CO_2 levels from 1000 to 1500 PPM are not uncommon.

3.2.2 Carbon Monoxide

Specifications:

Type of Measurement	Continuous data recording
Permissible exposure limits	Health Canada - 25 PPM for one hour period, and average 11 PPM over 8 hour period
Criteria for measurements	Measurements in suites (most applicable for buildings with underground parking garages, fuel-fired appliances, and heavy outside traffic areas) - intent to measure CO level in a "worse case condition" - spot check CO levels in garages when garage ventilation fans are off and on during the morning or evening peak use (7:00 to 9:00 or 16:00 to 18:00 hours) - record hours of ventilation system operation - locate sensing device in suites 0.5 meter away from corners (important to monitor at least one ground level suite)
Duration of measurement	Five to seven days
Sample size	A minimum of three suites per building (especially relevant in buildings having underground parking or which are in close proximity to heavy traffic) - two instantaneous samples from underground garage, data logging of one sample per suite
Indoor locations *(continuous measurements)*	- living area - basement, ground, and second floor most appropriate
Baseline measurement *(instantaneous measurements)*	- garage - outdoor facing traffic in the vicinity of five meters from the building
Type of equipment	Continuous data logger
Range and accuracy	0 - 100 PPM; ±1 PPM
Reporting	Full data plot during test period - extract maximum, minimum and average levels.

Notes:

Refer to manufacturer's literature for device operational instructions. Note that warning and alarm settings should be disabled on the CO data logger.

3.2.3 Formaldehyde

Specifications:

Type of Measurement	Average (continuous exposure)
Permissible exposure limits	Health Canada – target level is 0.05 PPM and action level is 0.1 PPM ASHRAE 62-1989 – 0.1 PPM average over 8 hours
Criteria for measurements	Measurements in occupied area (one measurement per suite) - bedrooms or living area - record hours of ventilation system operation - locate sensing device in the center of the room and at least a meter away from the operable windows - locate sensing device about 0.4 to 0.6 meter below the ceiling level - locate sensing device 0.5 meter away from corners of room
Duration of measurement	Five to seven days
Sample size	A minimum of three suites per building
Indoor locations	- master bedrooms or living area - select appropriate windward and lee-ward suites - ground, middle and top floors
Baseline measurement	0 PPM
Type of equipment	AQR PF1 Passive Dosimeter
Range and accuracy	0.02 to 10.0 PPM; ± 0.015 PPM
Reporting	Average concentration over test period

Notes:

Refer to supplier's literature for device operational instructions.

3.2.4 Volatile Organic Compounds (VOCs)

Specifications:

Type of Measurement	Air sampling
Permissible exposure limits	Ontario Ministry of Labour - 2 mg/m^3 total VOCs
Criteria for measurements	One sample per suite (3 in total); - record hours of ventilation system operation - locate sensing device in the centre of the room and at least a meter away from the operable windows
Duration of measurement	Five to seven days
Sample size	A minimum of three suites per building
Indoor locations	- master bedrooms or living area - select appropriate windward and leeward suites - ground, middle and top floors
Baseline measurement	not applicable
Type of equipment	passive dosimeters (GC-FID method for all three suites and GC-MS analysis for one suite) [3]
Range and accuracy	0 - 20 mg/m^3; ±5% full range
Reporting	Average TVOC levels in 3 suites; speciated VOC in one suite

Notes:

One GC-MS VOC analysis will be done to identify the concentrations of 26 common VOCs in a suite closest to the mid-height of each building (this is assumed to be at or near the neutral pressure plane of the building and will likely give the highest readings of the three suites selected). The VOCs that will be identified are as follows:

n-hexane	α-pinene	m-xylene	hexachloroethane
dichloromethane	tetrachloroethylene	o-xylene	p-dichlorobenzene
benzene	toluene	d-limonene	1,1,2,2-tetrachloroethane
n-decane	1,2-dichloroethane	1,3,5-trimethylbenzene	1,2,4-trichlorobenzene
trichloroethylene	ethylbenzene	m-dichlorobenzene	naphthalene
chloroform	p-xylene	pentachloroethane	

Note that the sampling procedure does not change for the GC-MS sample.

[3] Gas Chromatography - Flame Ionization Detection. GC-MS is Gas Chromatography - Mass Spectrometry

3.2.5 Air Temperature

Specifications:

Type of Measurement	Continuous data recording
Permissible exposure limits	ASHRAE - 21 to 24 °C depending on the season; Night setback of 2 to 4 °C
Criteria for measurements	One continuous data logged measurement per suite - instantaneous measurements in occupied area, bedrooms and living area - record temperature in the center of a room 1 m above floor
Duration of measurement	Five to seven days
Sample size	A minimum of three suites per building
Indoor locations	- master bedrooms or living and common area rooms - select appropriate windward and lee-ward suites - ground, middle and top floors
Baseline measurement	Outdoor air (hourly temperature data will be obtained from the weather station nearest to each building)
Type of equipment	T, RH & CO_2 Continuous data logger. Model YES-203
Range and accuracy	-35 to 95 °C; ±0.7 °C full range (NTC Thermistor: 10 ohms @ 25 °C)
Reporting	Full data plot during test period - extract maximum, minimum and average levels.

3.2.6 Air Temperature Distribution / Velocity

Specifications:

Type of Measurement	Instantaneous
Permissible exposure limits	ASHRAE 55-1992 for temperature and air distribution only - 21 to 24 °C depending on the season; air velocity at the diffuser not to exceed 0.3 m/s.
Criteria for measurements	Measurements in occupied area, bedrooms and living area - record air flow rate or velocity from fan coil unit or central forced air diffusers (if applicable) when the system is on - for units with undercut doors and ventilation from the corridor, measure air flow rates at the door undercut - record temperature distribution around the room. Four corners of the room 1 m above floor, center of window about 0.1 m away, and near the door.
Duration of measurement	Instantaneous measurements for the purpose of determining distribution profiles
Sample size	A minimum of three suites per building
Indoor locations	- master bedrooms or living area, and common area rooms - select appropriate windward and lee-ward suites - ground, middle and top floors
Baseline measurement	Still air (no measurement required)
Type of equipment	TSI Velocicheck Model 8330
Range and accuracy	0 - 40 °C; ±1 °C full range
Reporting	Temperature and velocity spatial distributions within test suites

3.2.7 Relative Humidity

Specifications:

Type of Measurement	Continuous data recording
Permissible exposure limits	ASHRAE - 25 to 65% depending on the season Health Canada -- 30 to 80% H summer; 30% to 95% winter
Criteria for measurements	Measurements in occupied area, bedrooms and living area - record RH when the ventilation air system is ON and OFF
Duration of measurement	Five to seven days
Sample size	A minimum of three suites per building
Indoor locations	- master bedrooms or living and common area rooms - select appropriate windward and lee-ward suites - ground, middle and top floors
Baseline measurement	Outdoor air (hourly temperature data will be obtained from the weather station nearest to each building)
Type of equipment	RH, T & CO_2 Continuous data logger. Model YES-203
Range and accuracy	10 - 90% (non-condensing); ± 4% full range (Sulfonated Polystyrene Wafer)
Reporting	Full data plot during test period - extract maximum, minimum and average levels.

3.2.8 Ventilation Rates

Specifications:

Type of Measurement	Instantaneous
Permissible exposure limits	ANSI/ASHRAE 62-1989 - 0.35 ACH but not less than 7.5 L/s/person
Criteria for measurements	Measurements in occupied area, bedrooms and living area - measure air flow rate from fan coil unit diffusers when the system is on and note outside air damper position to estimate percent outside air (if applicable) - measure air flow rate through door undercut when corridor ventilation is on and note air velocity and area of opening (if applicable). - measure air flow rate from corridor air grilles(if applicable) - measure air flow rate from bathroom fans(if applicable) - measure air flow rate from kitchen exhaust fans(if applicable)
Duration of measurement	Instantaneous
Sample size	A minimum of three suites per building
Indoor locations	- master bedrooms or living and common area rooms - select appropriate windward and lee-ward suites - ground, middle and top floors
Baseline measurement	Natural ventilation (fan system off)
Type of equipment	Sensitive air flow devices
Range and accuracy	0 - 200 L/s; ±0.5 L/s full range
Reporting	Instantaneous L/s from selected diffusers (as appropriate)

Notes:

Perform one PFT Test (Tracer Gas) in a ground-level suite to estimate the overall rate of air exchange in the suite. The test results will aid in the approximation of the air infiltration rate for the zones at the ground level, where they tend to be highest.

Note that the air velocity measurements already described in section 3.2.6 can be used to determine the ventilation rate supplied by the ventilation system, whether the air is supplied to the unit from the corridor via an undercut door or directly from suite fan coil units. The area through which the air is delivered must be measured to calculate an average flow rate from the velocity readings. Multiple air velocity readings should be taken to obtain a reasonable average.

Note that the CMHC Duct Test Rig will be used to measure the air velocity at several exhaust fans at one building to verify measurements made by other equipment.

3.2.9 Electro Magnetic Fields (EMF)

Specifications:

Type of Measurement	Instantaneous
Permissible exposure limits	No agreed upon limits - recommended level is 8 milligauss at 0.3 m away from the source - the World Health Organization recommends a level up to 1000 milligauss - Ontario Hydro recommends a level up to 20 milligauss - Swedish study pointed health risk at 3 milligauss - research ongoing
Criteria for measurements	Measurements in occupied area, bedrooms and living area in accordance with the IEEE recommended protocol for spot measurements (not a standard).
Duration of measurement	Instantaneous spot measurements
Sample size	A minimum of three suites per building
Indoor locations	- master bedrooms, living area - ground, middle and top floors
Baseline measurement	Readings with suite power off or outdoor readings
Type of equipment	Hand held, single-axis, induction coil EMF measuring device
Range and accuracy	0 to 1000 hertz; 0 - 1000 milligauss; ± 5% full range
Reporting	Average EMF levels (at 60 Hz) in each room.

3.2.10 Lighting levels

Specifications:

Type of Measurement	Instantaneous
Permissible exposure limits	IES suggested minimum lighting levels depend on activity within the common areas. National Building Code Section 9.
Criteria for measurements	Measurements in building common areas, corridors and stairwells only. - common area rooms - locate meter in the center of the room and at least a meter away from windows - locate sensing device at working (or reading) level - locate sensing device 0.5 meter away from corners - record weather conditions (available natural light)
Duration of measurement	Multiple instantaneous readings
Sample size	All common areas per test building
Indoor locations	- select appropriate widely-used common area rooms, corridors and stairways - ground, middle and top floors
Baseline measurement	N/A (ambient natural light which is variable)
Type of equipment	Electronic and analog light level meters. GE Triple Range 214 Light Meter
Range and accuracy	Multiple scales 0-1000 fc; ± 10% fc full scale
Reporting	Lighting distribution in common areas

Notes:

Refer to manufacturer's literature for device operational instructions.

3.2.11 Biological

Specifications:

Type of Measurement	Visual inspection of presence of fungi, mould and mildew
Permissible exposure limits	None. Occupant tolerance of fungi, mould and mildew varies tremendously
Criteria for measurements	Inspections in occupied area, bedrooms, living area, bathrooms and kitchen
Duration of measurement	Instantaneous
Sample size	A minimum of three suites per building
Indoor locations	- master bedrooms, living area, bathrooms and kitchen; checking particularly around windows, at corners, at carpets near outside walls, in kitchens and bathrooms, and inside closets on exterior walls - select appropriate windward and lee-ward suites - ground, middle and top floors
Baseline measurement	N/A
Type of equipment	N/A
Range and accuracy	N/A
Reporting	Observation, type of occupancy, occupancy moisture loads, type of ventilation systems

Notes:

Photographs will be taken of all observations.

4. AIRTIGHTNESS TESTS

CMHC's report on "Establishing the Protocols for Measuring Air Leakage and Air Flow Patterns in High-Rise Apartment Buildings" is an excellent guide to conducting airtightness tests and for prescribing suitable equipment for multi-unit residential buildings.[4] CGSB 149.10 Standard "Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method" is used as a guideline for performing the whole building airtightness test.[5]

One to three blower doors will be required to depressurize each building. Each fan must be capable of handling 5,000 L/s at 50 Pa pressure difference. For mid-rise buildings built after 1990, two blower doors should be able to conduct the full spectrum of airtightness tests.

The outdoor temperature should not be below 5 °C and the wind speed not more than 15 km/hr. Each blower door will require one attendant and an additional person may be required to coordinate the simultaneous operation of the blower doors. Outdoor pressure taps are required to be attached to at least four facades of the building at the main floor level and also one on the roof. The apartment doors leading to corridors are required to be open by 25 to 50 mm to allow equal depressurization across the exterior building envelope. Data will be recorded on the Multi-Unit Airtightness Test Form.

5. ENERGY AUDIT PROCEDURES

The majority of the information required to perform an energy analysis of the buildings comes from the as-built drawings. The energy audit forms accompanying this procedure are to be completed to supplement the information from the drawings.

The type of information that is required from an on-site audit includes:

- occupancy rate and type of occupancy (i.e., seniors vs. young couples with children)
- operational schedules for:
  - common area lighting and outside lighting
  - ventilation system and heating/cooling systems, including set points
  - DHW circulation pumps
  - parking ramp snow melting (if exists)
- condition of HVAC equipment and actual operation of controls
- thermostat setpoints (if applicable)
- accuracy of the as-built drawings

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[4] CMHC 1990. **Establishing the protocols for measuring air leakage and air flow patterns in high-rise apartment buildings.** Prepared by R.J. Magee and C.Y. Shaw of National Research Council of Canada for Canada Mortgage and Housing Corporation, Ottawa, Ontario

[5] CGSB 1986. **CGSB 149.10 Standard — Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method**, CGSB, Ottawa.

IAQ Surveys

BUILDING SURVEY FORM

I BUILDING COMMON AREAS

1. What year was the building constructed? _____
   a) Are the as-built design diagrams for this building available? yes / no
   b) Are the current design diagrams for this building available? yes / no
   c) Are the operating and maintenance manuals for the building's HVAC system available? yes / no
   d) Is there a routine maintenance program for the HVAC system? yes / no
2. Have any areas been recarpeted recently?
   a) If YES, did odours persist for more than a week after carpet was laid? yes / no
   b) If YES, describe locations:

   ____

3. Have any areas been repainted recently? yes / no
   a) If YES, did odours persist for more than a week after paint was applied? yes / no
   b) If YES, describe locations:

   ____

4. Has there been a recent or is there a regular cleaning process which uses large amounts of chemicals or solvents? yes / no
   a) If YES, what were the chemicals?

   Brand Names ____
5. Is there a fuel-fired central heating unit or DHW system? yes / no
   a) Is there any physical evidence of leakage of combustion gases from the furnace into the furnace or flue room or nearby areas? yes / no
   b) Is there an odour of combustion fumes in the room? yes / no
6. Is there an enclosed or underground parking garage? yes / no
   a) Are there vestibules leading to the garage ? yes / no
   b) Is it ventilated mechanically? yes / no
   c) Is the ventilation system effective? yes / no
   d) Was the ventilation system found in an inoperative state? yes / no
   e) Is the ventilation system turned off for periods? yes / no
   f) Is the ventilation system controlled? yes / no
   g) Are there carbon monoxide sensors in the garage which control ventilation? yes / no
   h) If so, have they recently been calibrated? yes / no
   i) Are there obstructions in the exhaust or air inlets? yes / no
   j) Are stack forces sucking air from the garage into the building? yes / no

7. Is there a garbage handling facility? yes / no
   a) Is the ventilation system off or ineffective? yes / no
   b) Is there an air flow pattern from the garbage rooms or chutes into the rest of the building? yes / no
8. Is there a pool, hot tub, sauna, or work out room? yes / no
   a) Describe the ventilation system.
   b) Does maintenance and cleaning appear to be regular and adequate? yes / no
   c) Are there any "mildew" stains on walls, ceilings, floors, fixtures, or such items such as shower curtains? yes / no
   d) Is there any condensation on walls , floors, windows, or ceiling? yes / no
   e) Does humidity appear to be adequate? yes / no
   f) Do any biodegradable products (wood, etc.) get wet regularly? yes / no
9. Are there any basement or sub-basement areas or crawl spaces with dirt floors? yes / no
   a) Are there occupied areas near by? yes / no
   If YES, describe locations:
   b) Are these spaces ventilated? yes / no
   If YES, describe.
   c) Are there musty odours in these areas or near by? yes / no
10. Are there rooms with sizable holes in the walls or floor, such as sump pits, gas and water entrances, cracks, etc.? yes / no
    a) If YES, describe location(s):
    b) Are these spaces ventilated? yes / no
    If YES, describe.
    c) Are there musty odours in these areas or near by? yes / no
11. Is there foam insulation in the walls of the building? yes / no
    a) The type of insulation is polyurethane / polystyrene / urea formaldehyde / unknown.
12. Do drawings show asbestos insulation for pipes, fire protection of structure, etc.? yes / no
    a) If YES, does inspection reveal loose fibers (especially near air handling equipment and ducts)? yes / no
13. Has there ever been a "water crisis" such as flood or overflow? yes / no
14. Are there any signs of moisture problems such as:
    a) stains or dampness on walls, floors or ceilings? yes / no
    If YES, where?
    b) stained, streaked, or damp carpets? yes / no
    If YES, where?
    c) mouldy odours, or musty smells? yes / no
    If YES, where?

II MECHANICAL SYSTEMS AND HVAC OPERATION

If the building contains two or more towers or wings, each controlled by a different HVAC system, a copy of this sheet should be filled out for each.

15. Describe the ventilation system: (i.e. central corridor, individual suite, or combination.)

    ____

    ____

    ____

    ____

16. Is the ventilation system controlled centrally or in the individual suites?
17. Are there any complaints regarding the noise levels? yes / no
18. Is the amount of fresh air used by the ventilation system the same all year round? yes / no
19. Is the ventilation system of the recirculating type? yes / no
    a) Does the HVAC system use an economizer? yes / no
    b) What is the maximum percentage of fresh air used? ______%
    c) What is the minimum percentage of fresh air used? ______%
    d) What is the present fresh air percentage? ______%
20. Air supplied to the floors by:

    constant volume systems / variable air volume (VAV) system / other / unknown.
21. Is there a corridor pressurization system? yes / no
    a) Is the "corridor-to-apartment" flow reversed? yes / no
    b) Are the doors to the suites undercut? yes / no
    c) What is the operation cycle (24 hour, seasonal)?
22. What is the temperature of tank supplying hot water to the building maintained? _____°C
    a) What is the fuel type?
23. Are there distinct fresh-air intakes for the building HVAC system? yes / no
    a) Are there intakes below third floor level and above a busy street? yes / no
    b) Are there intakes within 10 meters (30 feet) of the entrance or exit to a parking garage? yes / no
    c) Are there intakes within 10 meters (30 feet) of the exhausts of this or an adjacent building? yes / no
    d) Are intakes near standing water or a cooling tower? yes / no
    e) Is there a build up of organic debris near any of the intakes? yes / no
    f) Are there any other sources of pollution near any of the intakes? yes / no

24. Does this building have particulate (dust) filter system installed in the fresh air intake? yes / no
    a) Are the filters missing? yes / no
    b) Are the filters changed regularly as recommended by the manufacturer? yes / no
    c) Do the filters fit so poorly that air bypasses them at the edges? yes / no
    d) Are the filters matted or dirty? yes / no
    e) Are the filters wet? yes / no

25. Does this building have an central air-chilling system? yes / no
    a) Is the chilling system supposed to operate at this time of the year? yes / no
    b) Is the chilling system operating now? yes / no

    If YES, answer the questions below:
    c) Are the condensate trays cleaned regularly? yes / no
    d) Is there slime or growth in the condensate trays? yes / no
    e) Is there dirt on the cooling coils? yes / no
    f) Are there mouldy odours in the system? yes / no

26. Are the ventilation ducts or plenums insulated? yes / no
    a) Is the insulation on the inside and directly exposed to the moving air? yes / no
    b) Is it more than five years since the ducts or plenums were last cleaned? yes / no

27. Are there any signs of condensation in ducts? (Check cold spots such as near inlets and after cooling coils first.) yes / no

III INDIVIDUAL SUITES/UNITS

(survey for tenants of units tested)

Unit number and Location ______________________________

Please answer all questions by circling the answers required.

28. General observations
   a) Are there damp spots or mould on the walls or ceiling? yes / no
   b) Are any of the carpets, curtains, etc. damp? yes / no
   c) Are there many potted plants in this area? yes / no
   d) Is there mould on the plants or their pots or soil? yes / no
   e) Do mites appear to be on the plants? yes / no
      If YES, what type?
   f) Is there much dust visible on flat surfaces? yes / no
   g) Is there evidence of condensation on windows or walls? yes / no
   h) Do you use a fan to create more air movement? yes / no
29. Are there air supply diffusers? yes / no
   a) Are there complaints of odours coming from the supply air? yes / no
   b) Which of the following best describes the odour?
      auto exhaust / diesel fumes / furnace room / heating system / pet odours / body odour / mouldy or musty / chemical / like solvent / (wet) cement or plaster / dusty / chalky / cooking
   c) Can you see any of the following around the diffusers?
      mould / chalky dust / dirt marks yes / no
   d) Are any of the air supply diffusers blocked by furniture, paper, or other obstructions? yes / no
   e) If fresh air is supplied by an undercut door, is the area adequate? yes / no
30. Are there any air exhaust fans or louvers in unit or complaint area? yes / no
   a) Do they have a poor drain rate? yes / no
   b) Are there dirt marks around the air exhaust louvers? yes / no
   c) Are any of the air exhaust louvers blocked by furniture, paper, or other obstructions? yes / no
31. Has carpeting or furniture been installed in the last three months? yes / no
32. Are there large areas of particleboard sheathing or furnishings? yes / no
33. Have any areas been painted in the last three months? yes / no
34. Is there a gas stove in the units? yes / no
   a) Is there an exhaust fan to remove combustion gasses produced by the stoves? yes / no

35. Is there a wood or gas fireplace? yes / no
    a) Does it appear to be poorly ventilated? yes / no
    b) Does it appear to have an inadequate air supply? yes / no

36. Is there a freestanding heater (gas or kerosene)? yes / no

    If YES,

    a) Are these heaters used in anything but well ventilated spaces? yes / no
    b) Is there an odour of combustion fumes in the room? yes / no
    c) Is the room exhaust recirculated rather than directly expelled outdoors? yes / no

37. Is there a refrigerator in the unit? yes / no
    a) Are any of the refrigerator drains blocked? yes / no
    b) Are the drain pans wet or mouldy? yes / no

38. Are there small but steady leaks in, around, under or behind sinks, toilets, tubs, and/or sewers? yes / no

39. Are there poorly sealed mechanical/electrical chases or other entry paths for contaminants from outside the unit? yes / no

40. Are there humidifiers or dehumidifiers in the unit? yes / no

    If YES,

    a) Do the drip pans, coil or water in these units have accumulation of dust, slime, sludge or mould? yes / no

IV APARTMENT UNIT SURVEY FORM - INDOOR ENVIRONMENT

English Copy

APARTMENT UNIT SURVEY FORM - INDOOR ENVIRONMENT

Building Identification: ____________________

OCCUPANT INFORMATION

Respondent Name: (optional) | Date:

Unit No.: | Floor No.: | Location of unit: ❑ corner unit ❑ middle unit

How long have you lived here? | Number of occupants: ________ No. of Infants: ______

Is anyone home on weekdays? ❑ yes ❑ no | Does anyone have allergies? ❑ yes ❑ no

Does anyone smoke? ❑ yes ❑ no | If yes, describe: ____________

Does anyone have asthma? ❑ yes ❑ no | Do you have pets? ❑ yes ❑ no Type: ________

INDOOR COMFORT

Describe the usual temperature in your unit. ❑ OK ❑ too hot ❑ too cold ❑ inconsistent

How would you describe the air: ❑ OK ❑ stale ❑ stuffy ❑ drafty

How would you describe the summer humidity level. ❑ comfortable ❑ too dry ❑ too humid

How would you describe the winter humidity level. ❑ comfortable ❑ too dry ❑ too humid

Is there condensation on your windows in the winter? ❑ no ❑ bottom third only ❑ most of window

Have you noticed mould growth anywhere? ❑ no ❑ bathroom ❑ outside walls ❑ windows

Do you use a humidifier? ❑ no ❑ occasionally ❑ at night ❑ frequently

Do you use your kitchen exhaust fan? ❑ no ❑ only when cooking ❑ frequently

Do you use your bathroom exhaust fan? ❑ no ❑ occasionally ❑ frequently ❑ on with lights

Are there disagreeable odours in your unit? ❑ no ❑ occasionally ❑ frequently ❑ all the time

Please identify the odour: ❑ cooking ❑ car exhaust ❑ mouldy/musty ❑ sewage ❑ cleaning agents
❑ paint ❑ carpets ❑ cigarette smoke ❑ other: ____________

Do you have health problems that you attribute to the building air? ❑ no ❑ headaches ❑ tiredness ❑ nausea
❑ skin irritations ❑ itchy eyes ❑ sore throat ____________ ❑ coughing
❑ other:

When are these problems at their worst? ❑ spring ❑ summer ❑ fall ❑ winter

When is the air quality best? ❑ spring ❑ summer ❑ fall ❑ winter

Would you be interested in providing access to your unit for indoor air quality tests? ❑ yes ❑ no

(Our work may provide you with useful information on how to improve your indoor air quality)

Please return this form to your building superintendent as soon as possible.

French Copy

Sondage de la qualité de l'environnement Intérieur - édifice à logements

Identification de l'édifice:____

INFORMATION SUR LES OCCUPANTS

Nom du répondant: (facultatif)	Date:
No. d'appartement | Étage.:	Votre app. est situé: ❑ sur un coin ❑ entre deux app.
Vous habitez ici depuis quand? an(s)	Nombre d'occupants: ________ No. d'enfants: ______
Y a-t-il quelqu'un ici le jour? ❑ oui ❑ non	Y a-t-il quelqu'un qui souffre d'allergies? ❑ oui ❑ non
Y a-t-il un(des) fumeur(s)? ❑ oui ❑ non	Si oui, type: ____________________
Avez vous des animaux domestiques? ❑ oui ❑ non si oui, type:	Y a-t-il quelqu'un qui souffre d'asthme? ❑ oui ❑ non

COMFORT À L'INTÉRIEUR DE L'APPARTEMENT

Décrivez la température habituelle dans l'app.: ❑ comfortable ❑ trop chaud ❑ trop froid ❑ inconsistant

Décrivez la qualité de l'air.: ❑ bonne ❑ mauvaise ❑ remfermé ❑ trop de courrants d'air

Décrivez le taux d'humidité en été.: ❑ comfortable ❑ trop sec ❑ trop humid

Décrivez le taux d'humidité en hiver.: ❑ comfortable ❑ trop sec ❑ trop humid

Y a-t-il de la condensation sur vos fenêtres l'hiver? ❑ non ❑ au bas seulement ❑ recouverte complètement

Y a-t-il de la moïsissure à certains endroits? ❑ non ❑ salle de bain ❑ murs extérieurs ❑ fenêtres

Utilisez vous un humidificateur? ❑ non ❑ parfois ❑ la nuit ❑ fréquemment

Utilisez vous le ventilateur de la cuisine? ❑ non ❑ seulement lors de la cuisson ❑ fréquemment

Utilisez vous le ventialteur de la salle de bain? ❑ non ❑ parfois ❑ fréquemment ❑ (brancher avec la lumière)

Y a-t-il des odeurs désagréables dans votre logement ❑ non ❑ parfois ❑ fréquemment ❑ continuellement
S V.P. identifiez la(les) odeur(s): ❑ cuisson ❑ gaz d'échappement d'automobile ❑ moïsissures ❑ égouts
❑ produits de nettoyage ❑ peinture ❑ tapis ❑ fumée de cigarettes ❑ autres. ________________

Avez vous des problèmes de santé dont vous attribuez à la qualité de l'air dans l'édifice? ❑ non ❑ maux d tête
❑ fatigue ❑ nausée ❑ irritations cutanées ❑ démangeaison des yeux ❑ maux de gorge ❑ toux ❑ autres:

Quand souffrez vous le plus de ces problèmes? ❑ pringtemps ❑ été ❑ automne ❑ hiver
Quand l'air est il meilleur? ❑ pringtemps ❑ été ❑ automne ❑ hiver

Lors de cette étude, nous effectuerons des tests de qualité de l'air dans quelques logements. Accepteriez vou que l'on effectue des tests dans votre logement? ❑ oui ❑ non

S.V.P. retournez ce formulaire au surintendant de votre édifice aussitôt que possible.

Protocol for Field Investigations of Mid-Rise Multi-Unit Residential Buildings

General Building Data

Building Code	
Date of Audit	
Auditors	

Name of the Building ______________________

Address ______________________

City ____________ **Province** ____________

Postal Code ____________

Contact Name(s) ____________ **Phone** ( ) ____________

____________ **Fax** ( ) ____________

Units Monitored [ ] [ ] [ ] [ ]

Building Description

Year of Construction [ ]

Number of Stories [ ]

[ ]

Number of Units	
Bachelor	
1-bedroom	
2-bedroom	
3-bedroom	
Other	
TOTAL	

Type of Construction [ ]
1. wood frame
2. flat plate concrete (reinforced)
3. masonry and precast
4. other (specify) ____________

Compass orientation of front wall [ ]

Type of Foundation [ ]
1. partial basement
2. full basement
3. crawl space
4. slab on grade
5. combination (specify)
6. use (garage, mechanical, laundry, etc.)

Wind shielding [ ]
1. none
2. moderate
3. heavy
4. very heavy

Fuels by end use

Space heating [ ]

Make-up air heating [ ]

Hot water [ ]

Cooking/Fireplaces [ ]

1. Electricity
2. Natural gas
3. Oil
4. Other

Other comments

Heating system [ ]
1. forced air
2. baseboard
3. hydronic
4. other: ____________

Cooling system [ ]
1. window air-conditioners
2. central forced air
3. none
4. other:

Sketch of Building Layout

Floor / Elevation: ______ Building Code: ______

North

Protocol for Field Investigations of Mid-Rise Multi-Unit Residential Buildings

IAQ Test Report - Part 1

Field Inspection and Data Records

Continuous sampling of Carbon Dioxide, Carbon Monoxide, Relative Humidity and Indoor Temperature

Building Code	
Date of Audit	
Auditors	

For the installation of testing equipment follow the protocol provided for CO2, CO, RH and temperature.

Record the following information at the beginning of test period:

1. Unit Number					
2. Number of occupants					
3. Number of smokers					
4. Windows open or close during the visit					
5. Is there an exterior door in the test room(s)?					
6. Are there pets in the house? If so, how many?					
7. Occupancy profile -	number of occupants:				
	approximately period of time (%):				
8. Windows usually opened or closed?					
9. Location of Samplers	T, RH & CO2 unit				
(Room)	CO unit				
10. Deployment date					
11. Deployment time					
12. Instantaneous readings	CO	ppm			
	CO2	ppm			
	RH	%			
	Temp.	deg C			
13. Outdoor Basline Readings	CO	ppm			
	CO2	ppm			

Record the following information at the end of test period:

13. Retrieval date					
14. Retrieval time					
15. Instantaneous readings	CO	ppm			
	CO2	ppm			
	RH	%			
	Temp.	deg C			
16. Outdoor Basline Readings	CO	ppm			
	CO2	ppm			
17. Other observations and comments					

Protocol for Field Investigations of Mid-Rise Multi-Unit Residential Buildings

IAQ Test Report - Part 2

Field Inspection and Data Records

Instantaneous sampling of air temperature distribution, air velocity and ventilation rates

Building Code	
Date of Audit	
Auditors	

For the installation of testing equipment follow the protocol provided for air temperature distribution, air velocity and ventilation rates.

Record the following information:

1. Unit Number				
2. Temperature and Relative Humidity in:	Kitchen:			
	Bedroom 1:			
	Bedroom 2:			
	Living Room:			
	Bathroom:			
3. Living Area Temperature Distribution	Corner 1:			
Measure temperature at 3 elevations:	Corner 2:			
Near Ceiling / Mid height / Near Floor	Corner 3:			
	Corner 4:			
	Centre of Room:			
4. Living Area Velocity Distribution	Corner 1:			
Measure velocity at 3 elevations:	Corner 2:			
Near Ceiling / Mid height / Near Floor	Corner 3:			
	Corner 4:			
	Centre of Room:			
5. M. Bedroom Temperature Distribution	Corner 1:			
Measure temperature at 3 elevations:	Corner 2:			
Near Ceiling / Mid height / Near Floor	Corner 3:			
	Corner 4:			
	Centre of Room:			
6. M. Bedroom Velocity Distribution	Corner 1:			
Measure velocity at 3 elevations:	Corner 2:			
Near Ceiling / Mid height / Near Floor	Corner 3:			
	Corner 4:			
	Centre of Room:			
7. Is ventilation provided from the corridor air system?				
8. Average Ventilation Rate around door(L/sec):				
	Velocity readings:			
	Area:			
9. Bathroom exhaust fan flow rate (L/sec):				
	Velocity readings:			
	Area:			
10. Air Velocity at Supply Air Grilles				

Protocol for Field Investigations of Mid-Rise Multi-Unit Residential Buildings

Indoor Environment Test Report

Field Inspection and Data Records

Instantaneous sampling of EMF, Biologicals and common area lighting levels

Building Code	
Date of Audit	
Auditors	

For the installation of testing equipment follow the protocol provided for lighting levels, EMF and biologicals.

Record the following information during the test period:

1. Unit Number				
2. EMF Measurement (miligauss)	Kitchen:			
(Centre of room reading)	Bedroom 1:			
	Bedroom 2:			
	Living Room:			
	Bathroom:			
3. EMF Background (miligauss)	Kitchen:			
(Turn suite power off -	Bedroom 1:			
centre of room reading)	Bedroom 2:			
	Living Room:			
	Bathroom:			
4. Are there any signs of "biologicals"?	Kitchen:			
(Mould, fungus, mildew, water stains)	Bedroom 1:			
	Bedroom 2:			
	Living Room:			
	Bathroom:			
	Other:			

5. Lighting level measurements (foot-candles)	Corridors:	
(multiple readings per location)	Front Lobby:	
(include a sketches)	Elevators:	
	Elevator Lobbies:	
	Stairwells:	
	Laundry Room:	
	Recreational Rooms:	
	Other:	

Comments:

Protocol for Field Investigations of Mid-Rise Multi-Unit Residential Buildings

Multi-Unit Airtightness Test

Building Code	
Date of Testing	
Auditors	

Building Information

Envelope Surface Area: ________ Sq m

Volume of Tested Space: ________ Cubic m

Building Preparation

Opening	**Exists**	**Required Prep.**	**Done**	**Undone**	**Comments**
Fire places		close dampers			
Fuel fired appliances		turn off			
Plumbing traps		fill			
Exhaust fans(with damper)		none			
Continuous ventilators		seal			
Dryer vent (with damper)		none			
Window air conditioners		seal			
Windows and exterior doors		close and latch			
Interior doors		open			

Test Conditions

Indoor Temperature ________ degrees C

Outdoor Temperature ________ degrees C

Wind Speed: ________ kmh

Test Results

Press Diff (Pa)	Fan Flow Pressure (Pa)						Fan Flow Rate (3) (CFM)			Total Flow (CFM)	Corrected Flow (L/s)
	Fan 1		Fan 2		Fan 3		Fan 1	Fan 2	Fan 3		
										0	0
										0	0
										0	0
										0	0
										0	0
										0	0
										0	0
										0	0

Protocol for Field Investigations of Mid-Rise Multi-Unit Residential Buildings

Energy Audit

Building Code	
Date of Audit	
Auditors	

All building dimensions, construction details, equipment capacities and quantities will be obtained from the building as-built drawings. The following information is required to supplement and confirm this data only.

General Information:

Building Name: ______________________ Date: __________

Address: ______________________ Time: __________

______________________ Weather: __________

Building Age: __________ *- OAT:* __________

Building Type: ______________________ *- Wind:* __________

No. of Floors: __________ __________

Dimensions: ______________________ Floor Plan? __________

Calculated Gr Area: __________ ft^2 # units: __________

Floor-Ceiling Height: __________ ft # beds. __________

Wind Shielding: ______________________ Utility. Data? __________

Exterior Electrical: ______________________

____

____

Comments ______________________

____

____

____

Interior Loads & Scheduling:

Total Occupancy: ______________________

Breakdown Req'd? __________ if so, attach breakdown (no 1 BR, 2 BR, etc)

Lighting Schedules ______________________

____

No Fixtures & Loc ______________________ Fixture 1: __________

______________________ Fixture 2: __________

______________________ Fixture 3: __________

______________________ Fixture 4. __________

______________________ Fixture 5: __________

______________________ Fixture 6. __________

No Devices & Loc ______________________ Device 1. __________

______________________ Device 2: __________

______________________ Device 3. __________

______________________ Device 4. __________

______________________ Device 5: __________

Comments ______________________

____

HVAC Description & Schedules:

Cooling System: ____________________

Heating System: ____________________

DHW System: ____________________

Thermostats: ____________________

Vent. System: ____________________
(# diffusers per floor) ____________________

Exhaust System: ____________________

Water Use & Water Heating:

Faucet Types: ____________________
No. Faucets: ____________________ Per Floor / Total

Showerhead. Types: ____________________
No Showerheads: ____________________ Per Floor / Total

Toilet Types/Cap. ____________________
No. Toilets: ____________________ Per Floor / Total

DHW Tank Size: ____________________
Heater Capacity: ____________________
Energy Source: ____________________
Pump Size & Sch. ____________________
Insulation: ____________________
Supply Temp.: ____________________
No. of Washers: ____________________
Whirlpool, etc.? ____________________

Protocol for Field Investigations of Mid-Rise Multi-Unit Residential Buildings

Photo Log

Building Code	
Date of Audit	
Auditors	

Name of the Building ______________________________

Photo #_____ ______________________________

Photo #_____ ______________________________

Photo #_____ ______________________________

Photo #_____ ______________________________

Photo #_____ ______________________________

Photo #_____ ______________________________

Photo #_____ ______________________________

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