#5847

Final Report

Development of Design Procedures and Guidelines for Reducing Electric Demand by Air Leakage Control in High-Rise Residential Buildings

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EXECUTIVE SUMMARY

Concerned especially with reducing peak power demand, Ontario Hydro is exploring various energy conservation strategies and their potentials. The existing electrically heated multi-residential building stock accounts for more than 14% of the commercial sector's electrical energy consumption and a much greater share of the peak power demand. Improving the energy efficiency of high-rise buildings is an important component of the demand and supply management (DSM) strategy.

In most Ontario locations, peak space heating demand in high-rise residential buildings varies from 35 to 65 W/m^2 of floor space. During peak winter conditions, the air leakage component contributes to the heating load by 12 to 25 W/m^2 - roughly 25 to 40% of the peak heating demand. Therefore, the control of air leakage in buildings has become recognized as a key element in achieving energy conservation. Clearly, if high-rise buildings could be better sealed, the potentials for reductions in peak demand (plant capacity) and energy usage, and the associated costs, should be enormously attractive to building owners and the utility.

The project was initiated in July 1990 by Scanada Consultants Limited of Ottawa and CanAm Building Envelope Specialists Inc. of Mississauga. Objectives were to develop simplified air leakage assessment procedure and to demonstrate and to test impact of air leakage control measures in the field.

The project accomplished the following: (i) developed and validated the field procedures necessary to identify and assess the air leakage rate in buildings of eight storeys and higher; (ii) established a procedure to evaluate the various air leakage control strategies based on potential cost benefits; and (iii) demonstrated air leakage control in two high-rise residential buildings with the results of the impact on peak power demand, energy consumption, indoor air quality, and of course the building airtightness. The project has helped to remove some of the uncertainties and shown the potentials for conservation are indeed considerable.

Assessment Procedure

A simplified air infiltration estimation procedure was developed, based primarily on equivalent air leakage area and local net pressure distribution. The air leakage rate at a given location depends on the infiltration driving forces (stack, wind and mechanical ventilation) and the characteristics of the opening in the building envelope. A simplified network of air-flow paths can be established using the following information: climate and exposure, building types, building form, building dimensions, surface to volume ratios, shafts, and envelope types, windows and doors, envelope crack lengths, openings, and make-up air strategies. The algebraic sum of air-flow through these paths must always be equal to zero. By applying the mass balance equation, the component of air infiltration which would be occurring during the peak winter condition can be determined. This air-flow rate is responsible for the space heating load due to uncontrolled infiltration. Any reduction in this infiltration flow should decrease the heating requirements for the building. The procedure was simplified and developed into a practical application tool which can be utilized by assessors and air leakage control contractors. The outline of this assessment procedure is presented in the Figure 1.

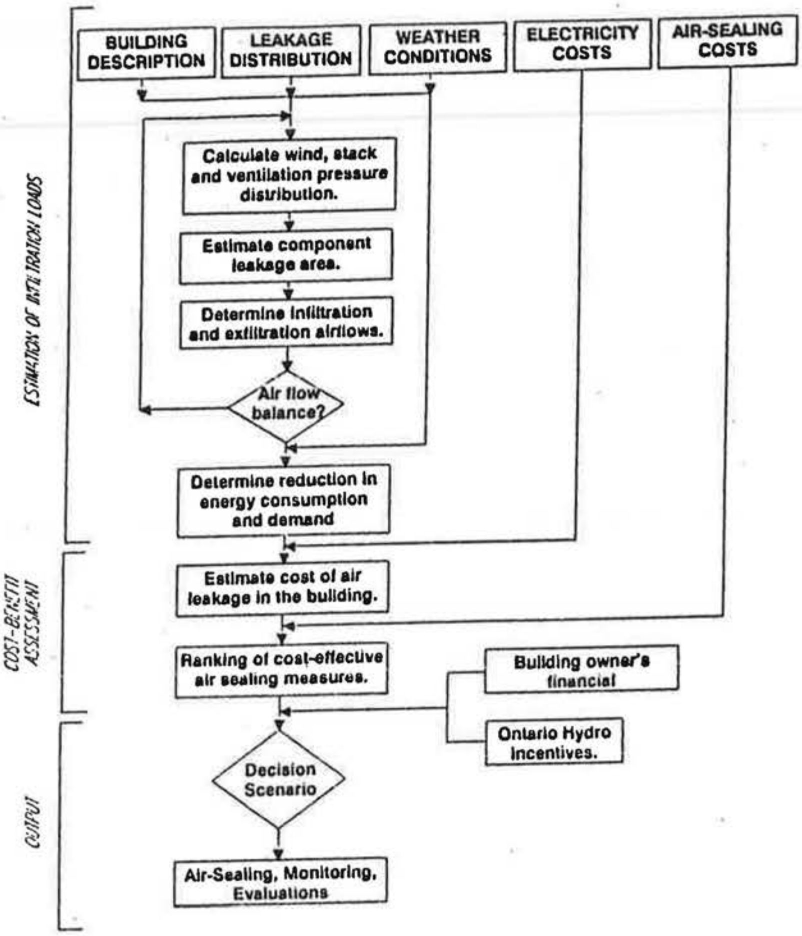


Figure 1: Procedure for Air Leakage Assessment and Control in High-Rise Residential Buildings.

Field Demonstration and Results

Two buildings were selected for the demonstration of air-sealing work. One building was located in Ottawa and the other was in Toronto. First, the estimation of air leakage rates was performed using the assessment procedure. Based on these estimations, air-sealing priorities were determined and a work plan was developed. The "whole building fan test" was conducted to determine the airtightness before and after air-sealing in order to refine and validate the assessment method. (The fan test is costly and is not a normal part of the new assessment procedure.) Based on airtightness results, the peak heating demand was calculated.

The continuous monitoring of energy and power consumption in these two buildings through the winter months showed a peak demand reduction in the Donald Street building of 85 kW, and a 42 kW reduction in the Bridleview building as a result of the air sealing as shown in Table 1. Figure 2, 3 and 4 shows the comparison of measured and estimated reductions in energy and power consumption for both the case buildings.

Table 1: Summary of Measured Energy Consumption Before and After Air Sealing.

	Peak Demand				Energy Consumption During Heating Season (kWh)	
	Before Air Sealing (kW)	After Air Sealing (kW)	Difference in Demand (kW)	Percentage Reduction	Difference in Energy (MWh)	Percentage Reduction
Donald Street Building (Ottawa)	772	687	85	11.0%	165	12.0%
Bridleview Building (Toronto)	496	454	42	8.5%	63.3	6.5%

Based on these monitored results, the air leakage assessment procedure was modified slightly to reflect the practical aspects regarding the airtightening of buildings. The assessment method was able to predict the potential savings in energy consumption within 5 to 10%.

Based on the successful demonstration of air-sealing work and the assessment procedure, it can be concluded that air leakage control or weatherization offers a potential to reduce the peak electric demand by 4 to 10 W/m^2 of floor space depending on the location and building characteristics. A simplified analysis of Ontario's high-rise residential building stock suggests an air leakage control potential of roughly 6 W/m^2 of floor space.

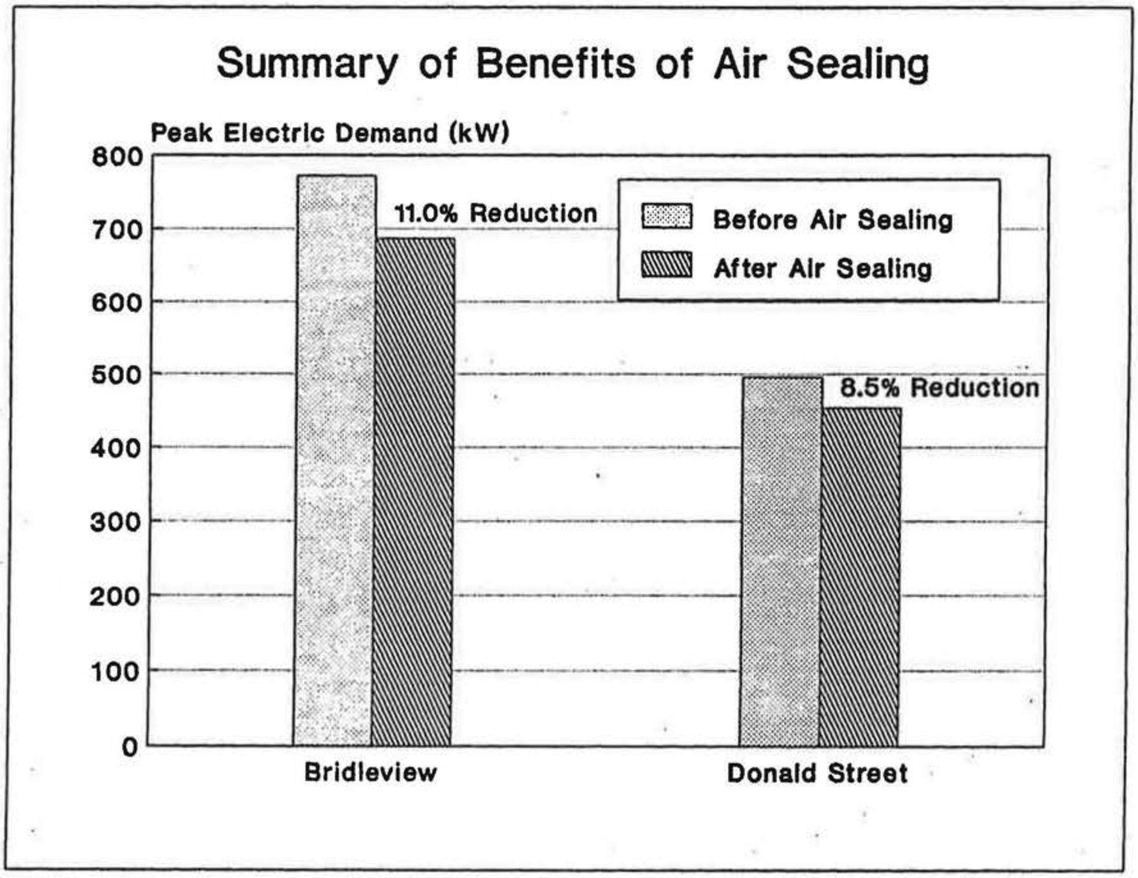


Figure 2: Summary of Measured Peak Power Demand Before and After Air Sealing.

Reductions in Peak Power Demand
(W/m2 of floor area)

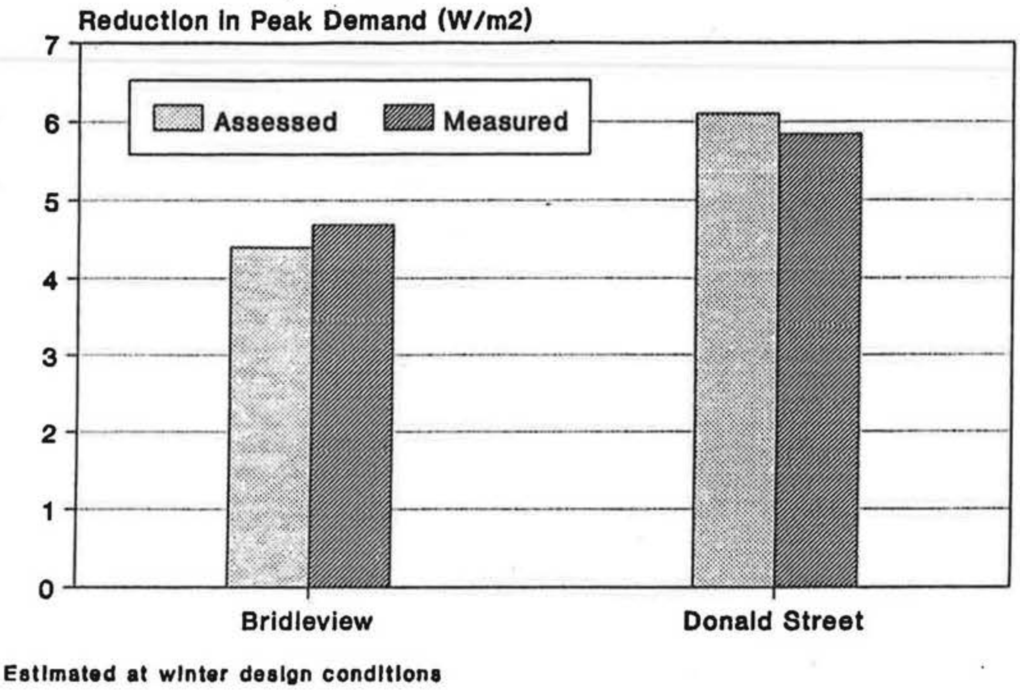


Figure 3: **Reductions in peak electric demand for four buildings. (W/m^2 of floor area)**

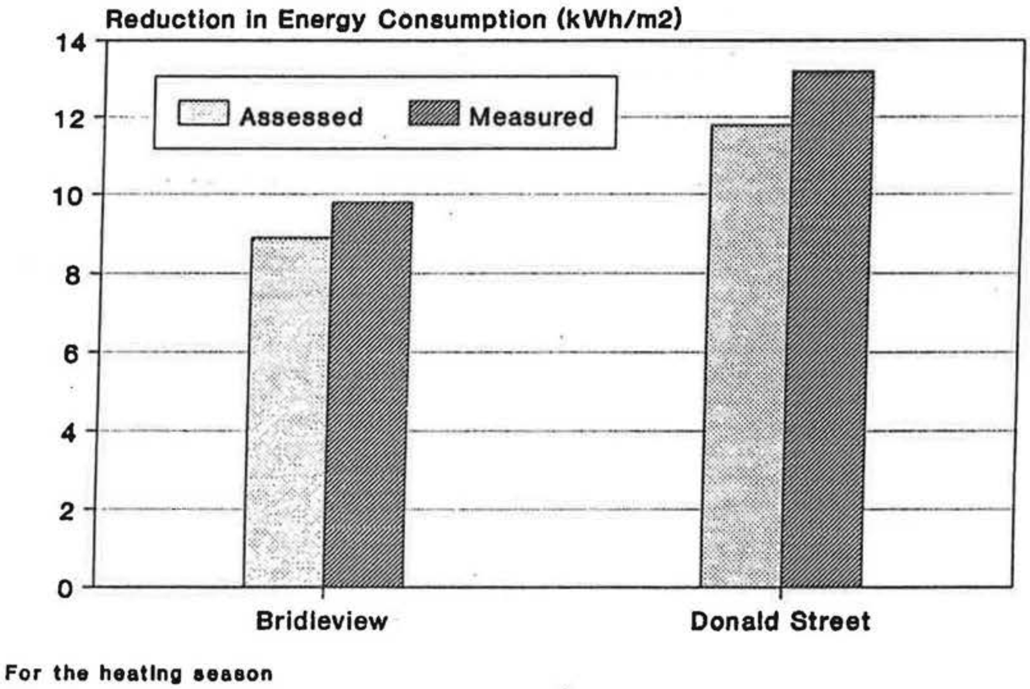
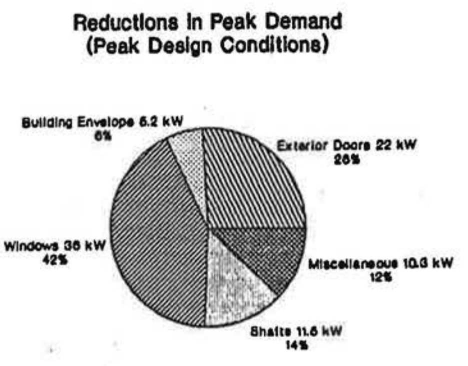


Figure 4: Reductions in space heating energy during the heating season. (kWh/m^2 of floor space)

Cost-Benefit Assessment
251 Donald Street



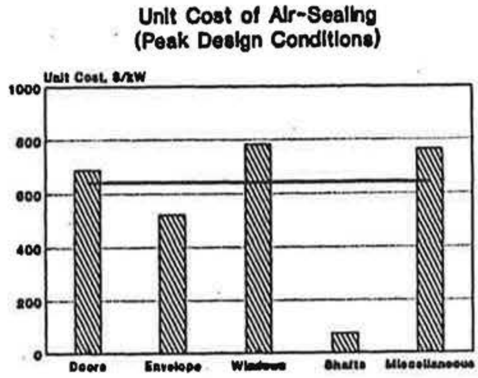


Figure 5: Priority of air sealing measures for the Donald Street Building.

Cost-benefit assessment showed that the average cost of air-sealing varied from $645 to $880 per kW of demand reduction for the two test buildings. The sealing of elevator shafts (top, bottom and external walls), garbage chutes (top and bottom) and stairways was the most cost effective air-sealing practise in both buildings. The second best methods were the sealing of exterior envelope, windows and doors, based on cost and potential peak demand savings. The priority of air-sealing measures was determined using the cost-benefit assessment. Figure 5 shows an assessment of Donald Street Building.

Indoor air quality tests showed that the air sealing of the building had no negative impact on the general conditions of comfort and air quality in both buildings as summarized in Table 2. In both these buildings, it was also observed that the air sealing had reduced the movement of stale odours. In fact, the sealing allowed for more consistent adjustment of air supply to the apartments.

Table 2: Summary of Indoor Air Quality Results After Air Sealing.

	After Air Sealing
1. Indoor room temperature	slightly increased
2. Relative humidity	increased
3. Carbon dioxide	slightly increased
4. Carbon monoxide	slightly increased
5. Formaldehyde	slightly increased
6. Radon (basement + ground)	no change

The implementation of a high-rise leakage control (weatherization) program must be done with full consideration of issues related to performance contracting, training of air-sealing assessors and air leakage control contractors, and quality control. Effective implementation of such a program would benefit Ontario Hydro and the building owners.

RÉSUMÉ

Par souci de réduire la demande de pointe, Hydro-Ontario étudie présentement différentes stratégies d'économie d'énergie et leurs possibilités. Les ensembles de logements collectifs chauffés à l'électricité accusent plus de 14 p. 100 de la consommation d'énergie du secteur commercial et une part beaucoup plus considérable de la demande de pointe. Le relèvement de l'efficacité énergétique des tours d'habitation constitue une importante composante de la stratégie de la gestion de l'offre et de la demande.

Dans la plupart des municipalités de l'Ontario, la demande de pointe en matière de chauffage pour les tours d'habitation fluctue entre 35 et 65 W/m^2 de surface de plancher. En période de pointe l'hiver, les fuites d'air contribuent à accroître la charge de chauffage de 12 à 25 W/m^2, soit environ de 25 à 40 p. 100 de la demande de pointe en chauffage. Remédier aux fuites d'air dans les bâtiments est donc reconnu comme élément clé de l'objectif d'économiser l'énergie. De toute évidence, si l'étanchéité à l'air des tours d'habitation pouvait être relevée, les perspectives de réduire la demande de pointe (capacité des usines) et la consommation d'énergie, et ses coûts, devraient susciter énormément d'intérêt chez les propriétaires d'immeubles et les services publics.

La recherche, amorcée en juillet 1990 par les firmes Scanada Consultants Limited d'Ottawa et CanAm Building Envelope Specialists Inc. de Mississauga, avait pour objectifs, d'une part, d'élaborer une méthode simplifiée d'évaluer les fuites d'air et, d'autre part, de démontrer et de tester sur les lieux l'incidence des mesures d'élimination des fuites d'air.

Voici par quoi s'est soldée cette recherche: (i) mise au point et validation des méthodes nécessaires pour caractériser et évaluer sur place les taux de fuite d'air des bâtiments de huit étages ou plus; (ii) établissement d'une méthode d'évaluation de diverses stratégies d'élimination des fuites d'air fondée sur une analyse des coûts-avantages; et (iii) démonstration de l'élimination des fuites d'air dans deux tours d'habitation, et répercussions sur la demande de pointe, la consommation d'énergie, la qualité de l'air intérieur et, évidemment, l'étanchéité à l'air des bâtiments. Les travaux de recherche ont permis de dissiper certains doutes et de déterminer l'ampleur considérable des possibilités d'économie.

Méthode d'évaluation

Les travaux ont débuté par l'élaboration d'une méthode simplifiée de détermination des infiltrations d'air, fondée principalement sur la surface de fuite équivalente et la distribution de la pression locale nette. Le taux de fuite d'air d'un endroit donné dépend des forces motivant l'infiltration (tirage, vent, et ventilation mécanique) et des caractéristiques de l'ouverture dans l'enveloppe du bâtiment. Un réseau simplifié des mouvements de l'air peut s'établir à l'aide d'information concernant le climat et l'exposition, le genre de bâtiment, la forme du bâtiment, la taille du bâtiment, le ratio surface-volume, les cages, le type d'enveloppe, les portes et fenêtres, les longueurs des fissures de l'enveloppe, les ouvertures, et les stratégies d'admission d'air de compensation. La somme algébrique des débits d'air empruntant ces voies doit toujours donner zéro. En s'en remettant à l'équation de l'équilibre statique, la composante des infiltrations d'air qui surviendraient en période de pointe l'hiver peut être déterminée. Ce débit d'air explique la charge de chauffage des locaux attribuable aux infiltrations incontrôlées. Toute réduction de ces infiltrations réduira les besoins de chauffage du bâtiment. La méthode a été simplifiée de façon à offrir un outil d'application pratique aux estimateurs et entrepreneurs chargés d'éliminer les fuites d'air. La figure 1 donne un aperçu de cette méthode d'estimation.

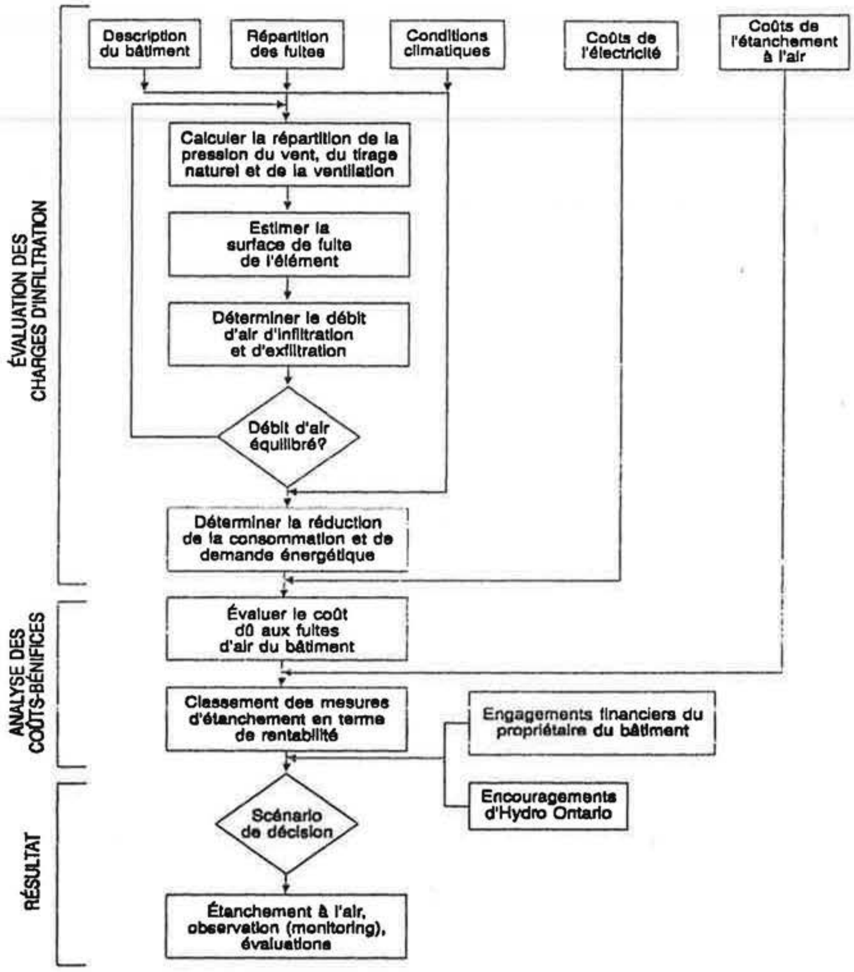


Figure 1 : Méthode de détermination et d'élimination des fuites d'air dans les bâtiments résidentiels de grande hauteur.

Démonstration sur les lieux et résultats

Deux bâtiments ont été retenus dans le cadre des travaux de démonstration des travaux d'étanchéification à l'air, l'un étant situé à Ottawa et l'autre à Toronto. D'abord, il a fallu établir, à l'aide de la méthode d'évaluation, les taux de fuite d'air. L'estimation a ensuite permis de fixer les priorités d'étanchéification à l'air et de dresser un plan de travail. Tout le bâtiment a été soumis à l'essai par ventilateur de manière à en déterminer l'étanchéité à l'air avant et après les travaux d'étanchéification, et à pourvoir affiner et valider la méthode d'évaluation. (L'essai par ventilateur s'avère coûteux et ne fait pas normalement partie de la nouvelle méthode d'évaluation.) Les résultats d'étanchéité à l'air ont ensuite servi à calculer la demande de pointe en chauffage.

La vérification continue de la consommation énergétique de ces deux bâtiments pendant les mois d'hiver a permis de constater, après les travaux d'étanchéification, une réduction de la demande de pointe de 85 kW dans le bâtiment de la rue Donald et de 42 kW dans celui de Bridleview, comme en fait foi le tableau 1. Les figures 2, 3 et 4 comparent les réductions mesurées et estimées de la consommation d'énergie à l'égard des deux bâtiments en cause.

Tableau 1 : Résumé de la consommation d'énergie mesurée avant et après les travaux d'étanchéification à l'air

	Demande de pointe				Consommation d'énergie pendant la saison de chauffage (kWh)	
	Avant (kW)	Après (kW)	Différence de la demande (kW)	Réduction en %	Différence en énergie (MWh)	Différence en %
Bâtiment de la rue Donald (Ottawa)	772	687	85	11,0	165	12,0
Bâtiment de Bridleview (Toronto)	496	454	42	8,5	63,3	6,5

D'après ces résultats surveillés, la méthode d'évaluation des fuites d'air a été légèrement modifiée pour tenir compte des aspects pratiques de l'étanchéification des bâtiments. La méthode d'évaluation permettait de prévoir, avec un écart de 5 à 10 %, les économies possibles en matière de consommation énergétique.

Le succès remporté par le programme pilote de travaux d'étanchéification à l'air et la méthode d'évaluation permet de conclure que l'élimination des fuites d'air ou l'étanchéification fait miroiter la perspective de réduire la demande de pointe en électricité de 4 à 10 W/m^2 de surface de plancher, compte tenu de l'endroit et des caractéristiques du bâtiment. Une analyse simplifiée du parc des tours d'habitation de l'Ontario laisse entrevoir des possibilités d'aboutir sur ce plan à une réduction d'environ 6W/m^2 de surface de plancher.

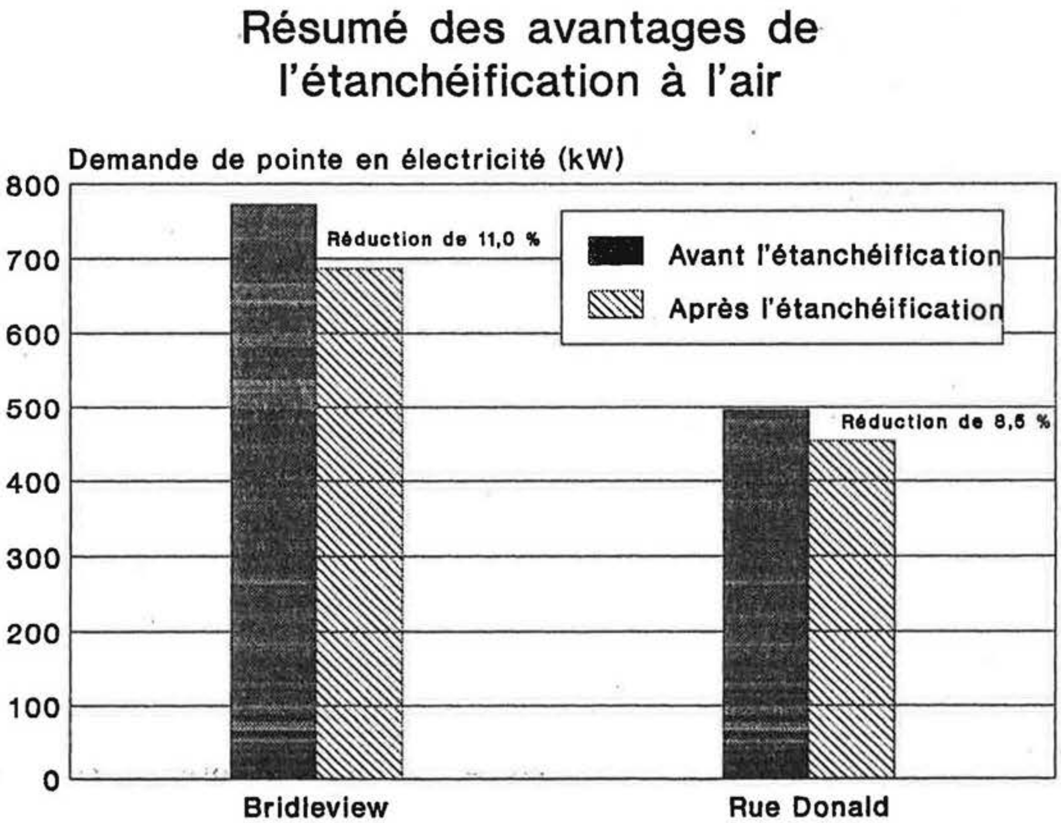
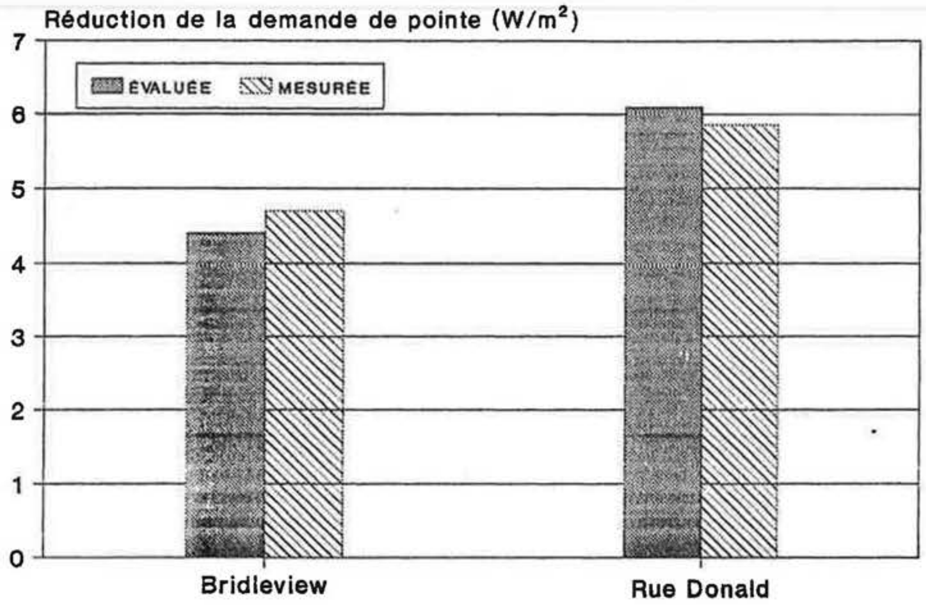


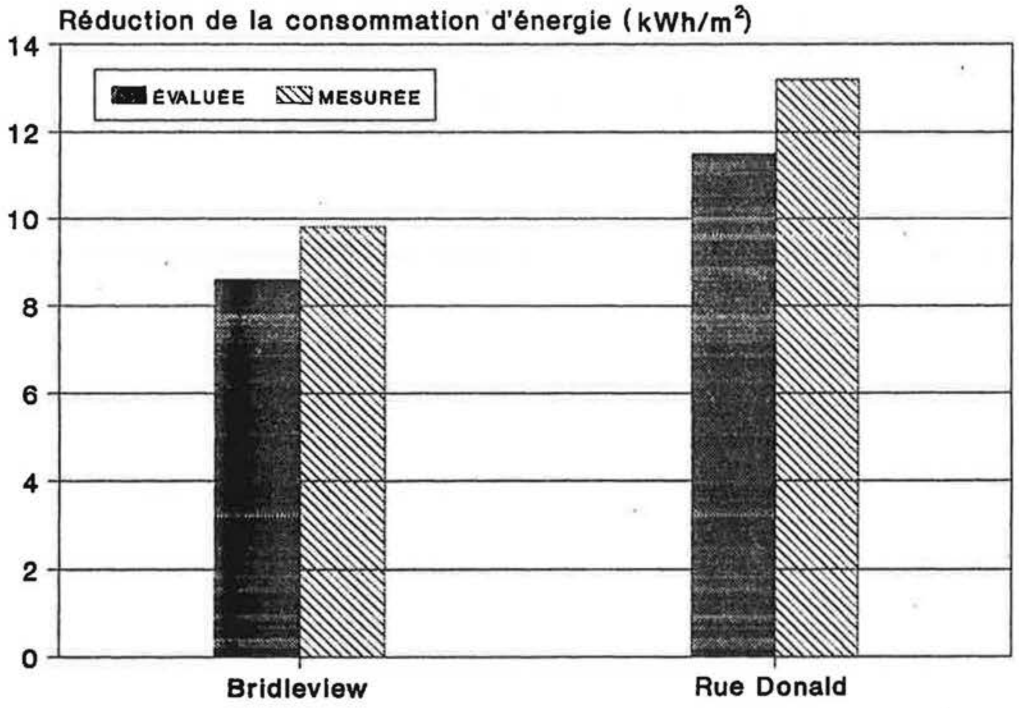
Figure 2 : Résumé de la demande de pointe d'énergie mesurée avant et après les travaux d'étanchéification à l'air

Réductions de la demande de pointe en énergie
(W/m² de surface de plancher)



Estimations des conditions de calcul en hiver

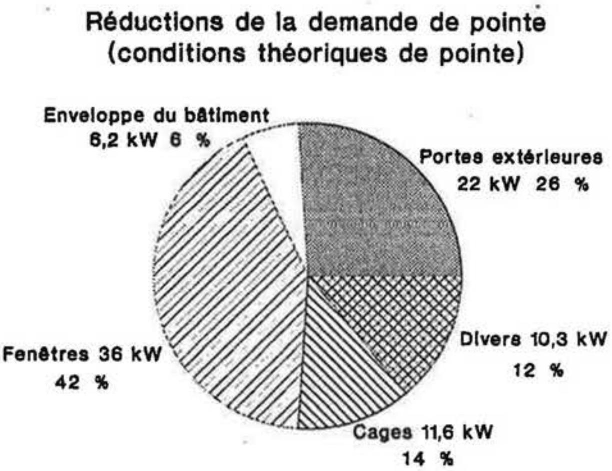
Figure 3 : Réductions de la demande de pointe d'électricité pour quatre bâtiments (W/m² de surface de plancher)



Pour la saison de chauffage

Figure 4 : Réductions de la consommation d'énergie consacrée au chauffage des locaux pendant la saison froide (kWh/m² de surface de plancher)

Analyse coûts-avantages
251, Rue Donald



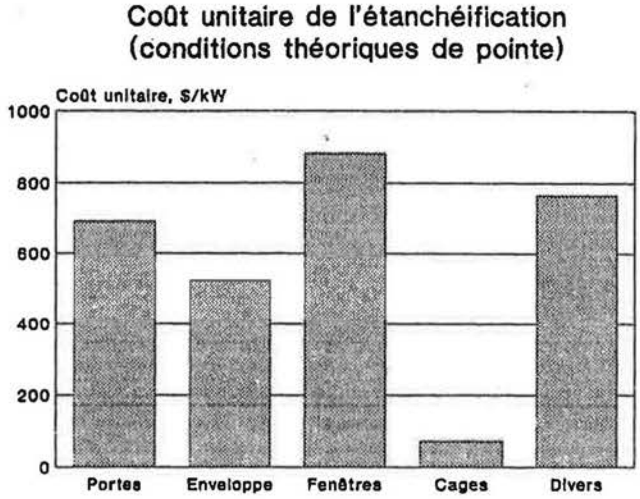


Figure 5 : Priorité des mesures d'étanchéification à l'air du bâtiment de la rue Donald

L'analyse coûts-avantages révèle que le coût moyen d'étanchéification des deux bâtiments en cause varie de 645 $ à 880 $ par kW de réduction de la demande. Dans les deux cas, la mesure la plus efficiente portait sur l'étanchéification des cages d'ascenseurs (le haut, le bas et les murs externes), des vide-ordures (le haut et le bas) et des cages d'escaliers, et la deuxième meilleure sur l'étanchéification de l'enveloppe extérieure, des portes et fenêtres, d'après les économies de coût et la réduction de la demande de pointe possibles. La priorité des mesures d'étanchéification a été déterminée en fonction de l'analyse coûts-avantages. La figure 5 fait état de l'évaluation du bâtiment de la rue Donald.

Les tests de qualité de l'air intérieur montrent que l'étanchéification du bâtiment n'exerce aucun effet négatif sur le confort et la qualité de l'air des deux bâtiments, suivant le tableau 2. Il a été observé que l'étanchéification des deux bâtiments avait contribué à réduire la circulation d'odeurs d'air vicié. En fait, l'étanchéification a permis de régler plus uniformément l'alimentation en air des appartements.

Tableau 2 : Résumé des résultats de qualité de l'air intérieur après les travaux d'étanchéification

	Après l'étanchéification
1. Température ambiante intérieure	Légère augmentation
2. Humidité relative	Augmentation
3. Dioxyde de carbone	Légère augmentation
4. Monoxyde de carbone	Légère augmentation
5. Formaldéhuyde	Légère augmentation
6. Radon (sous-sol et sol)	Aucun changement

La mise en oeuvre d'un programme d'élimination des fuites d'air dans les tours d'habitation doit s'effectuer en considérant tous les aspects de l'impartition, de la formation des estimateurs experts en la matière et des entrepreneurs chargés de l'étanchéification, ainsi que du contrôle de la qualité. La mise en application efficace d'un tel programme profitera à Hydro-Ontario et aux propriétaires d'immeubles.

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ACKNOWLEDGEMENT

The "*Development of Design Procedures and Guidelines for Reducing Electric Demand by Air Leakage Control in High-Rise Residential Buildings*" was conducted for Ontario Hydro. The research, technical development, field tests, data analyses and project coordination was performed by Scanada Consultants Limited. The field assessment and air-sealing was performed by CanAm Building Envelope Specialists Inc.

The outcome of this project is very much the product of a team effort. Among many participants, contributors and reviewers, the following deserve special mention:

From Ontario Hydro, Mike Jacobs supervised, coordinated and reviewed all stages of this project; Bob Brockman assisted in energy monitoring and data collection; Masoud Almassi assisted in review of progress reports and provided program direction.

The building airtightness tests were conducted as part of a test program of the Canada Mortgage and Housing Corporation. Jacques Rousseau of CMHC provided the technical guidance.

Tom Lanczi of Con-Serve Group reviewed the air-sealing assessment procedure and checked its field viability. Rick Quirouette of Morrison Hershfield Limited reviewed the progress reports and provided valuable comments.

Phil Renaud, Robert Tuttle, Andre Lambert and all of Ottawa-Carleton Regional Housing Authority were willing and eager participants in this project; they assisted and made all arrangements for conducting field tests at 251 Donald Street.

Cam Robinson, George Lamrock and Bob Strand of 2500 Bridletown Circle provided necessary help during air-sealing work and made all arrangement for conducting field tests at the building.

Special appreciation must be accorded to the occupants of 251 Donald Street and 2500 Bridletown Circle for their patience and participation in this project.

The Scanada project team was comprised of Anil Parekh, Robert Platts, Eric Bonnyman, Ken Ruest, Kathy Seifried and David Kayll. Tony Woods led the CanAm team.

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1991

1. INTRODUCTION

Air infiltration and ventilation has a profound influence on both the internal environment and on the energy needs of buildings. Unnecessary high air change rates present an excessive burden on the building's heating (or cooling) system, resulting either in an unnecessary waste of energy or in the inability of the heating (or air conditioning) system to satisfy thermal and comfort requirements. Problems relating to moisture migration, cold drafts and a generally uncomfortable living or working environment may also be experienced with high air leakages. Therefore, the control of air leakage in buildings has become a key element in achieving both energy conservation and indoor air quality.

Air exchange in buildings occurs as a consequence of natural air infiltration and through the use of "designed" ventilation. The natural air infiltration is the uncontrolled flow of air through penetrations in the building envelope caused by the action of wind and temperature difference. Hence, air infiltration provides little control over the pattern of air movement within the buildings and it is also a very haphazard approach to ventilation which cannot be relied upon to provide a steady supply of fresh air.

A survey of four electrically heated high-rise residential buildings[1] in Ontario has shown that the peak heating demand varies from 35 to 70 W/m^2 of floor space. During the peak winter conditions (below -18°C ambient temperature and greater than 5 m/s or 18 km/hour wind velocity), the air infiltration component contributes to the heating load by 12 to 25 W/m^2 - roughly 25 to 40% of peak heating demand. Any reduction in such uncontrolled air infiltration, without sacrificing indoor air quality, will have the potential of reducing the overall peak heating demand.

Despite the importance of the process of air infiltration, it is still an aspect of building science about which there is considerable uncertainty. In part, this problem has been made difficult by the diverse range of buildings, each constructed according to widely varying construction practices. The quantification of infiltration flows is difficult due to the complexities of the flow mechanisms. It is this lack of design considerations in the building construction which has frequently resulted in higher heating consumption, as well as moisture and air quality problems. Clearly, good predictive design methods will minimize the problems associated with air infiltration in both new and existing high rise buildings.

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[1] The high-rise building is defined as a building with eight storeys or higher (20 m or higher).

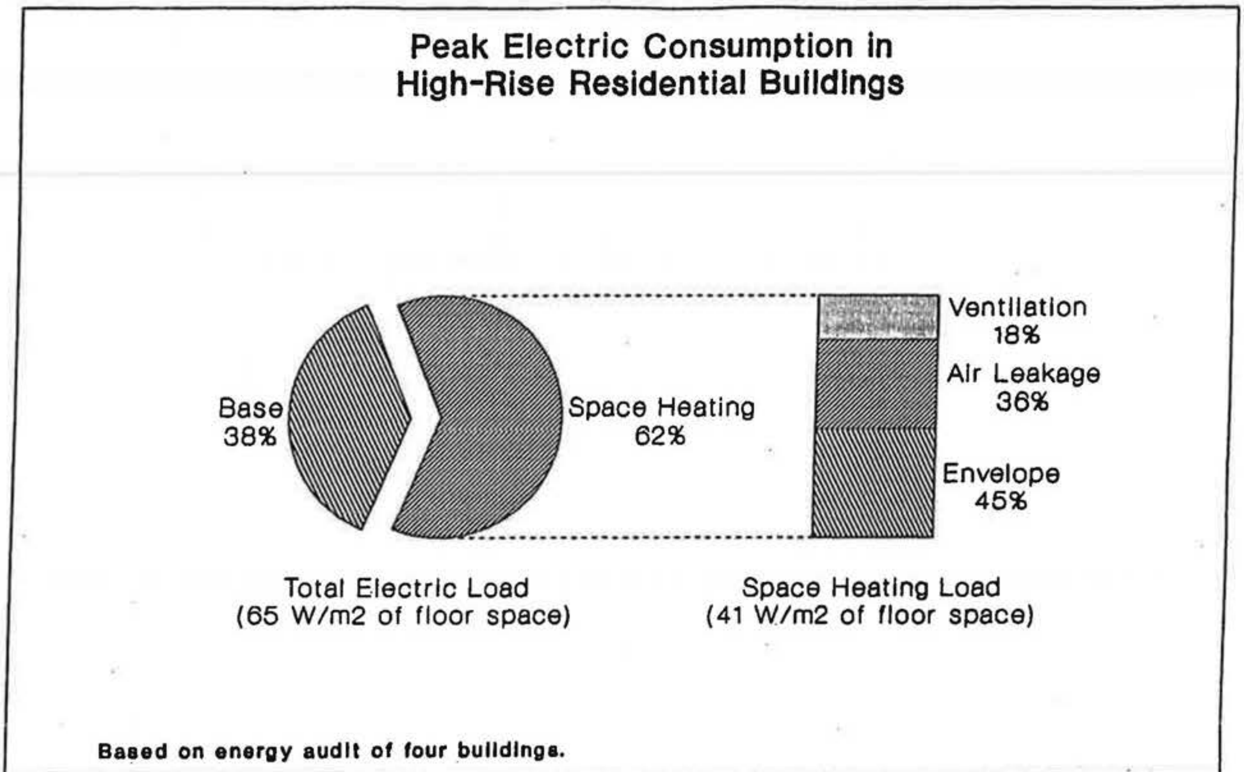


Figure 1: The peak electric demand in high-rise residential buildings varies between 55 and 100 W/m^2 of floor space during the heating season --- the air leakage component is approximately 12 to 25 W/m^2.

Ontario Hydro is vigorously promoting electrical efficiency improvement programs to better manage its electrical generation and demand. Air leakage control in high-rise residential buildings offers an important load reduction opportunity to Ontario Hydro. The load reduction is achieved primarily through improvements in the efficiency of space heating electricity use. The demand reduction opportunities offered by air leakage control (weatherization) in buildings need detailed examination in developing a sound DSM program.

The following elements are important in establishing such a program:

- an air leakage assessment procedure to establish the load reduction potential and the benefits to Ontario Hydro and building owners;

- the demonstration of air leakage control in high-rise buildings and verification of the electrical load reductions; and

- a preliminary assessment of how much impact such "weatherization" can have on Ontario's high-rise residential building stock.

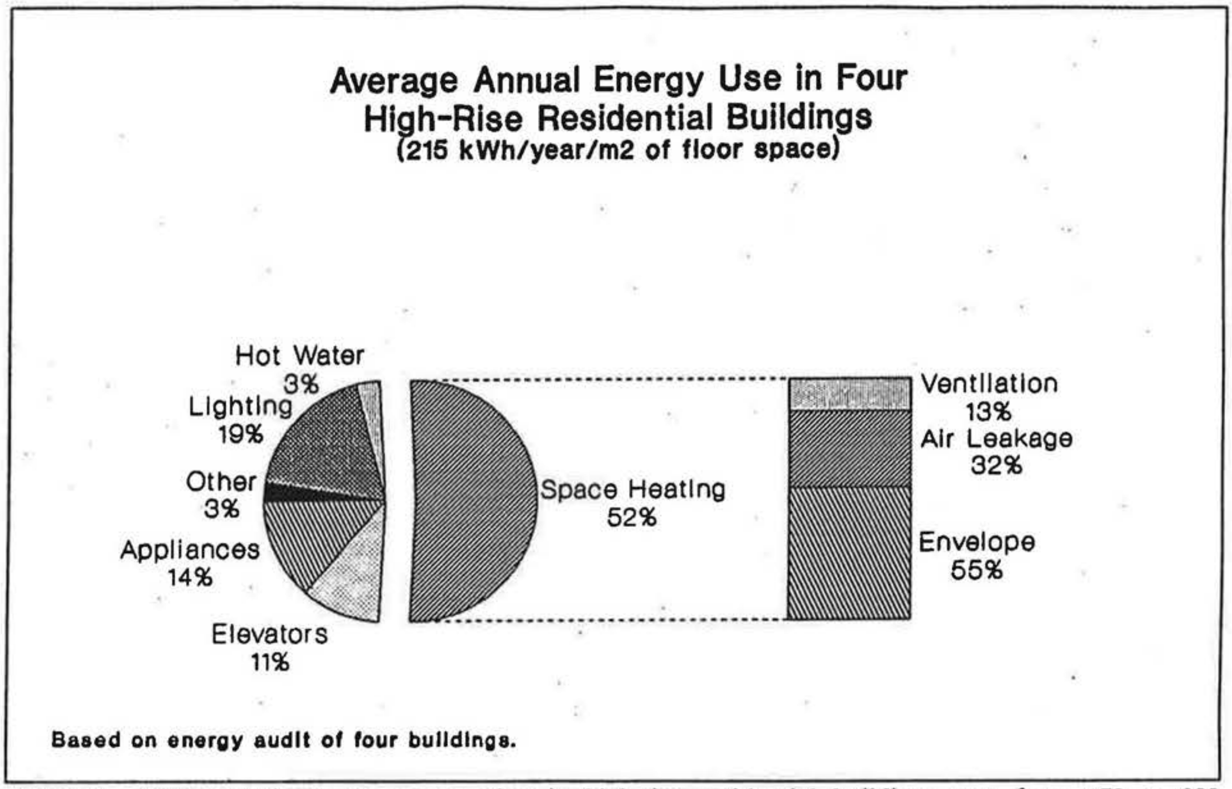


Figure 2: The annual energy consumption in high-rise residential buildings vary from 170 to 300 kWh/year/m^2 of floor space depending on the climate.

1.1 Objectives

The objectives of this project were set out as follows:

- to develop practical design procedures for estimating potential reductions in peak power demand and energy consumption through air-sealing of existing high-rise residential buildings;
- to develop from that an air-sealing assessment procedure and practical guidelines for air sealing practitioners;
- to test airtightness of two buildings before and after air-sealing to verify the assessment procedure and show the reductions in electric demand; and
- to calculate the potential benefits to Ontario Hydro in terms of peak demand reductions and energy conservation through air-sealing Ontario's high-rise residential stock.

1.2 Approach

The project objectives were achieved by implementing the work plan shown in Table 1. Literature on state-of-the-art technology was reviewed to gain insight into the current research and practical developments related to modelling and assessment of air infiltration in high-rise buildings. The project team negotiated with several building owners for their willingness to participate in this demonstration project. After three to four months of rigorous negotiations, the project team was able to obtain permission from two high-rise building owners for their participation. A twenty-one storey building located in Ottawa, owned and operated by Ottawa-Carleton Regional Housing Authority (OCHRA), and a ten storey building in Toronto, Bridleview Condominiums, were selected for the demonstration of air leakage control. Ontario Hydro assisted in the installation of continuous monitoring of electrical consumption.

Table 1: Scheduled Work Plan.

WORK TASKS	
Task 1:	Establish the knowledge base and develop first concepts for air-infiltration model for high-rise buildings.
Task 2:	Select two electrically heated typical high-rise residential buildings for demonstration of weatherization concepts. Install and commission continuous monitoring equipment for electrical consumption in these buildings.
Task 3:	Develop the "first-cut" air-sealing assessment procedure and predict the potential reductions in peak heating demand and energy conservation for two buildings.
Task 4:	Conduct the following field tests of high-rise buildings before air-sealing: - air leakage detection: visual, thermographic and selective depressurization - predictive diagnosis using the air-sealing assessment procedure - air-quality tests (radon, formaldehyde, CO, CO_2, temperature and relative humidity) - selection of air-sealing techniques and methods - perform the whole building airtightness tests using the CMHC protocol for high-rise buildings
Task 5:	Implement air-sealing work on these buildings.
Task 6:	Conduct the filed field tests after air-sealing of these buildings: - balancing and tuning of mechanical ventilation system - measure changes in the space heating load, mechanical ventilation load, and energy consumption due to reduction in air leakage - air-quality tests at locations done before air-sealing - perform whole building airtightness tests using the CMHC protocol for high-rise buildings
Task 7:	Verify the predictions with measured energy consumption data and modify the air-sealing assessment procedure.
Task 8:	Prepare the air-sealing assessment procedure, design guidelines and a manual for air-sealing practioners.
Task 9:	Estimate the preliminary potential benefits to Ontario Hydro in terms of reductions in peak demand and energy consumption through air-sealing of Ontario's electrically heated high-rise residential building stock.
Task 10:	Prepare a final report and present results.

A detailed air-flow model was developed for high-rise buildings. This model was used to estimate the air leakage rate in buildings during peak design conditions. The model requires the distribution of air leakage paths in the building. Field inspection and energy audit was performed on these test buildings. A "first-cut" estimation of air leakage rate in the building was determined for different winter weather conditions such as cold, moderate and mild. Several sets of field tests were performed to establish the "*before and after air-sealing*" characteristics of the buildings. Air quality tests were performed to study the effects of air-sealing on indoor air quality. Airtightness tests were conducted to characterize the *whole* building envelope airtightness. The air-sealing work was implemented in pre-determined steps to obtain maximum insight into the importance of several types of building components in air-leakage control.

Energy consumption monitoring was started about a month prior to air-sealing and continued for more than four months after air-sealing. The monitored energy consumption data were compared before and after air-sealing to estimate the reduction in peak heating demand. A comparison was also made with the "first-cut" estimates. The air-flow modelling was modified and calibrated accordingly. A simplified air-sealing assessment procedure was developed for practical applications. Design guidelines and a manual provide the necessary tools for the estimation of potential benefits and the implementation of air leakage control in high-rise residential buildings.

1.3 Report Organization

The project deliverables are submitted in the following components:

1. Air leakage control estimation procedure for the air-sealing practioners to evaluate potential reductions in the peak power and energy consumption, to estimate the preliminary air-sealing costs, and to prioritize the air sealing work.

   High-Rise Residential Weatherization: Procedure for Assessing Air Leakage and Potential Control in Electrically Heated Residential Buildings of Eight Storeys And Higher. This report provides the necessary forms for field inspection, calculation of air leakage rate, estimation of peak power and energy consumption, the costs of air-sealing and prioritizing the air-sealing work. An accompanying **Guide** describes the use of these forms. The report includes the following sections:

   - Building Audit and Field Inspection
   - Estimation of the Uncontrolled Air Leakage Component
   - Determination of Air Sealing Priorities
   - Development of Work Plan for Air Sealing of the Building
   - Guide

2. Final project report gathers all relevant aspects of the project (this document). It is divided into the following sections:
   - Development of air-sealing assessment procedure
   - Field demonstration
   - Implementation of air sealing in high-rise residential buildings
   - Validation of assessment procedure
   - Conclusions and recommendations

2. DEVELOPMENT OF AIR-SEALING ASSESSMENT PROCEDURE

Air leakage is often of considerable importance to the energy performance of a building. The inward leakage of air is known as air infiltration and the outward air leakage is known as exfiltration. Mechanical ventilation is considered distinct from air leakage and is the intentional supply or removal of indoor air.

In most electrically heated high-rise residential buildings in Ontario, the peak space heating demand varies from 35 to 70 W/m^2 of floor space. During the peak winter conditions (below -18 deg C ambient temperature and more than 18 km/hour wind velocity), the air infiltration component contributes to heating load by 12 to 25 W/m^2 - roughly 25 to 40% of peak heating demand. Any reduction in such uncontrolled air infiltration, without sacrificing indoor air quality, will have the potential to reduce the peak heating demand.

Air leakage can occur through pores in materials, cracks, holes, or other openings. In some cases, such as cracks around windows or doors, air-leakage paths can be identified and measured; but in other situations the nature and location of the leakage openings are not known in detail. The openings may be torturous paths through porous materials, thin laminar passages formed by cracks and joints, or holes of various shapes and sizes.

The heating loads due to uncontrolled infiltration predominantly depend on the in and out air-flows from the building at the peak ambient conditions. The cold air infiltrating into the building adds to the heating load while the air exfiltrating out of the building causes loss of heat to the outdoors. A simplified calculation method developed here is based on the building envelope air leakage area and pressure distribution. Flow balance of air inflow and outflow through the building is used to determine the neutral pressure plane. The net air inflow or outflow is then used to estimate the infiltration heating loads.

The air sealing estimation procedure addresses four concerns:

1. What is the air leakage in the building?
2. How much reduction in peak demand is possible with air leakage control?
3. What will be the air sealing priorities and effectiveness for achieving maximum ratio of reduction in kW to the air sealing costs?
4. Is the estimation procedure simple enough to be used expressly for practical field applications and what would be the sensitivity of such estimates in energy and power reduction?

The air leakage control in buildings also raises the following questions from the users and air-sealing practitioners:

- How tight can buildings be and still supply adequate ventilation and maintain indoor air quality?

- How much of an impact will weatherization have on the utility's demand and supply management objectives?

This section describes the theoretical aspects of air infiltration calculations, the development of a detailed air infiltration model, and a simplified air infiltration assessment procedure.

2.1 Theoretical Considerations

There are three key factors which affect air infiltration in high-rise buildings:

- the overall tightness of the building,
- the climatic (temperature and wind) influence, and
- the topographic environment in which the building is located.

Air infiltration in the building constitutes part of the space-conditioning load (heating plus cooling) depending on the influence of the above factors [ASHRAE, 1989]. Air infiltration increases a building's thermal load in three ways. First, the incoming air must be heated or cooled from the outdoor air temperature to the indoor air temperature. Second, air exchange changes the moisture content of the building, particularly in the summer when the humid outdoor air needs dehumidification. In winter months, the heating load due to humidification should also be considered as an additional power consumption due to air infiltration. Finally, air exchange can increase the thermal load by decreasing the performance of the envelope insulation system. However, the effect of such insulation deterioration is difficult to quantify.

The rate of energy consumption due to air leakage is therefore a combination of sensible and latent heat load, which is given as

$$q=q_s+q_l \quad (1)$$

The energy required to warm outdoor air entering by infiltration to the temperature of the room is given by:

$$q_s=Q\rho C_p(T_i-T_o) \quad (2)$$

where,

q_s	=	sensible heat load, W
Q	=	airflow rate, L/s
ρ	=	air density, kg/m^3 (about 1.2)
C_p	=	specific heat of air, kJ/(kg C) (about 1.0)
T_i	=	indoor temperature, (20 °C)
T_o	=	outdoor temperature

Using standard air ρ = 1.2 kg/m^3, and C_p = 1.0 kJ/(kg C), the above equation simplifies to:

$$q_s=1.2Q(T_i-T_o) \quad (3)$$

When moisture must be added to the indoor air to maintain winter comfort conditions based on indoor relative humidity, the energy needed to provide humidification is calculated by:

$$q_l=Qh_{fg}\Delta W \quad (4)$$

where,

q_l = latent heat load, W
h_{fg} = latent heat of vapour, kJ/kg (about 2450)
ΔW = humidity ratio of indoor air minus humidity ratio of outdoor air, kg of water/kg of dry air

Using the standard air ρ = 1.2 kg/m^3 and latent heat of vapour h_{fg} = 2450 kJ/kg, the above equation reduces to:

$$q_l=2940Q(W_i-W_o) \quad (5)$$

The outdoor temperature used for designing the heating system depends on the location and this can be found from published weather data found in the National Building Code or the Ontario Building Code [NBC 1990 and OBC 1990]. Table 3 lists the winter design conditions for selected Ontario locations. The estimation of heating loads due to infiltration predominantly depends on the in and out air-flows (Q) from the building. It is this air leakage rate, Q, which needs to be properly estimated in high rise buildings. Determination of this unknown air leakage rate, Q, is one of the prime objective of this project. The following sections deals with the method for determining the air leakage rate in the building.

2.1.1 Weather Conditions

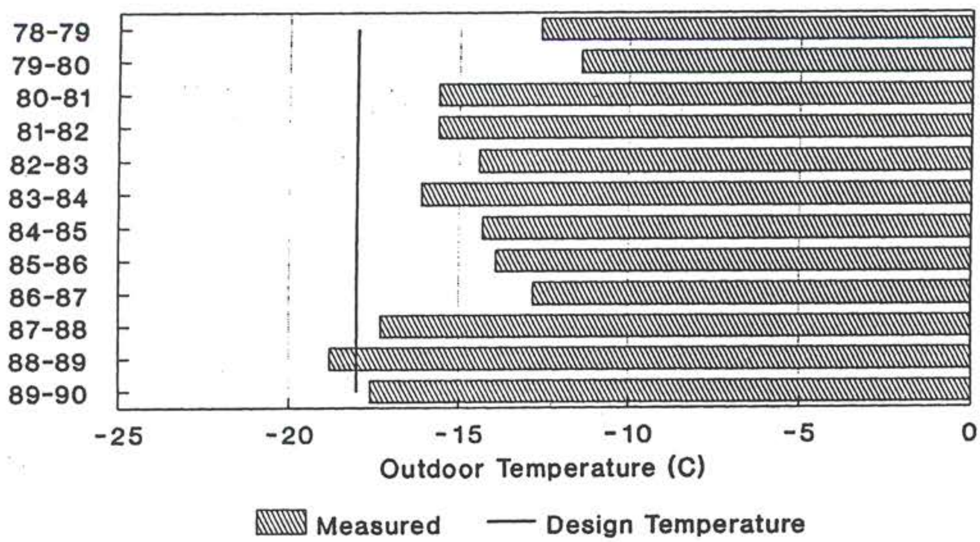
Air leakage in the building is solely dependent on the combined pressures due to wind and temperature difference. The incidence of peak heating demand in a building may occur during the following ambient conditions:

1. very cold and high wind speed for a period of more than one hour (severe weather condition - such weather may occur once in 100 chances)
2. very cold and moderately windy (chances are 1 in 15)
3. very cold and calm (quite a normal condition and chances are 1 in 10)
4. moderately cold but windy (chances of such weather are 1 in 10)
5. mild and windy (one chance in 10)

The peak generating requirement for the utility generally occurs during working days (Monday to Friday) between the hours of 07:00 and 23:00 in Ontario. Persistence of any of the first three weather conditions, for more than 18 to 24 hours, may result in an overall increase in the power generation requirement due to additional requirements for building space heating due to higher rates of air infiltration [Stricker 1975]. The electrical system condition in Ontario generally falls on the coldest working weekday of the winter. The average temperature during the 16-hour system peak period (07:00 to 23:00) was recorded for past 12 heating seasons in Toronto. Figure 3 shows the scatter of the data, which average -15.1 þ 2.3 °C. The mean can be compared to Toronto's design temperature of -18 °C.

The above mentioned weather conditions are primarily responsible for increasing the uncontrolled air leakage in buildings. As an example, the air leakage at an indoor/outdoor temperature difference of 22 deg C (with 2.5 m/s wind) is 0.12 L/s.m^2, while at a temperature difference of 37 deg C (with 6.7 m/s wind) the rate is 0.20 L/s.m^2 of floor area. The heating system is generally designed to meet this later peak heating requirement, where the leakage role has risen exponentially.

In high-rise buildings, the space heating loads are calculated using the January 2.5% design criteria as recommended by ASHRAE design guidelines and various building codes and practises. The air-infiltration loads are generally determined using the January 2.5% design criteria (meaning that the ambient conditions remained for at least a period of 2.5% of the time -- approximately 18 hours -- in January), and an average value of wind speed occurred during this time. The seasonal energy consumption due to air leakage may be related to the average infiltration rate during the heating season, but the heating system may have to be sized to care for the maximum air leakage rate to be expected over a 12- to 24-hour period. Table 2 lists the climate conditions for some Ontario locations.



Data gathered from Ontario Hydro

Figure 3: Average temperature during system peaks in Toronto during the heating season.

Table 2: Winter design conditions for selected Ontario locations.

Location	Winter Design Temperature 2.5%, deg C	Wind Speed m/s		Degree Days below 18 C
		1 in 10	Mean	
Ajax	-20	26	12.5	4080
Barrie	-24	18	8.4	4575
Brampton	-19	22	10.2	4321
Burlington	-17	24	11	3818
Cambridge	-18	20	9.2	4100
Kapuskasing	-33	19	8.8	6438
Kingston	-22	23	10.6	4251
Kitchener	-19	20	9	4146
London	-18	24	11.3	4133
Mississauga	-18	24	12	4000
Niagara Falls	-16	23	10.5	3662
Ottawa	-25	22	12.5	4634
Sudbury	-28	21	9.7	5043
Toronto	-18	25	11.5	3646
Windsor	-16	21	9	3622

Mean wind speed over a period of 3600 seconds or more.

2.1.2 Infiltration Driving Forces

The forces driving air exchange are exerted by the natural actions of wind and temperature (stack effect) and by the pressures induced by the operation of mechanical ventilation systems. The indoor and outdoor pressure difference at a location depends on the magnitude of these driving forces as well as on the characteristics of the openings in the building envelope. The net pressure difference between inside and outside depends on the air-flow balance. The air-flow into the building equals the air-flow out. Considerable simplification of the true pressure distribution is necessary to predict the peak infiltration rates into the building. Wind effects due to momentarily occurring high velocity wind gusts are difficult to evaluate; however, due to the thermal mass of the building such brief wind gusts may not have noticeable impact on space heating loads or peak heating demand [Hutcheon and Handegord 1983].

Wind Pressures

Wind is characterised by random fluctuations in velocity which, when averaged over a fixed period of time, holds a mean value of speed and direction. The strength of wind is a function of height, terrain, and shielding. On impinging the surface of an exposed building, wind deflection induces positive pressure on the windward side, and negative on the leeward side. Pressures on the other sides are negative or positive, depending on the wind angle and building shape. The time-averaged pressure acting at any point on the surface of a building can be represented by the equation

$$P_w=(\rho C_{pw} V_H^2)/2 \tag{6}$$

where,

P_w = surface pressure due to wind, Pa
C_{pw} = pressure coefficient
V_H = wind speed, m/s

Generally, "on-site" data for the wind speed and pressure coefficient is rarely available and therefore measurements taken from the nearest weather station must be used in determining the local wind speeds. The shielding effects of trees, shrubbery, and other buildings in the vicinity produce large-scale wind separation which alters the wind speed and direction locally. Therefore, the metrological wind speed data must be corrected to account for the building height, terrain and shielding. The following method is suggested here to determine the local wind pressures [ASHRAE 1989]:

The wind speed V_{met} from the metrological station is measured at a height H_{ref}, usually about 10 m, in open flat terrain. The reference wind velocity at the same height in the local building terrain V_{ref} is given by:

$$V_{ref}=A_o V_{met} \tag{7}$$

where constant A_o depends on local terrain roughness. The wind speed V_H at the wall height H depends on the velocity profile and is described as,

$$V_H=V_{ref}(H/H_{ref})^a \tag{8}$$

Table 3: Coefficients for determining wind velocity, V_H.

Terrain	A_o	a
Airport (building in a flat terrain)	1.0	0.15
Suburban (cluster of low-rise buildings)	0.60	0.28
Urban (high-rise buildings in populated districts)	0.35	0.40

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The wind pressure coefficient (C_{pw}) depends on building shape, wind direction, and the influence of nearby buildings, vegetation, and terrain features. The air infiltration rates can be reasonably estimated using the average wind pressure coefficients derived for high-rise buildings [ASHRAE 1989]. The wind angle is measured from a perpendicular to the main dimension of the building (generally front dimension of the building). The orientation of building is determined using the ASHRAE terminology as shown in Figure 5.

For the design heating load, the wind pressure coefficient is generally estimated at an average of the wind angle 0 and 30 degrees. The average wind pressure coefficient, C_{pw}, ranges from 0.25 to 0.40 for most buildings, in most Ontario locations [derived from explanation presented in NBC 1985].

The wind pressure is calculated using equation (6). The time-averaged wind pressures do provide a satisfactory estimation of infiltration loads in high-rise buildings. Figure 4 shows a typical wind pressure distribution.

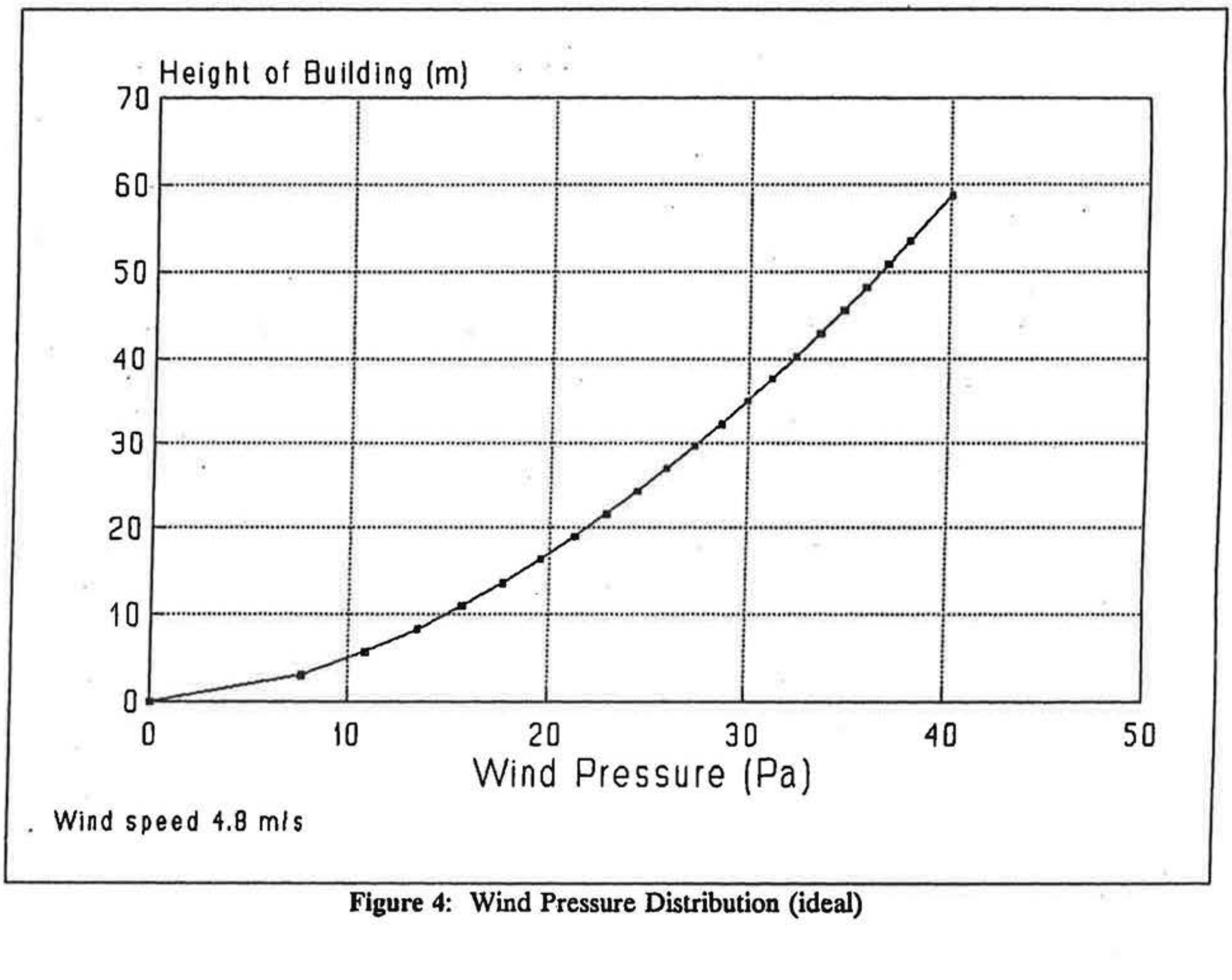


Figure 4: Wind Pressure Distribution (ideal)

Table 4: Averaged Wind Pressure Coefficient, C_{pw}.

Wind Angle (degree)	L/W = 1	L/W = 0.25	L/W = 4
0	0.62	0.62	0.62
10	0.60	0.60	0.60
20	0.58	0.55	0.58
30	0.5	0.40	0.52
40	0.37	0.25	0.45
50	0.25	0	0.37
60	0	-0.25	0.22
70	-0.2	-0.50	0.10
80	-0.37	-0.62	-0.10
90	-0.6	-0.62	-0.25

L is the length, and W is the width of the building.

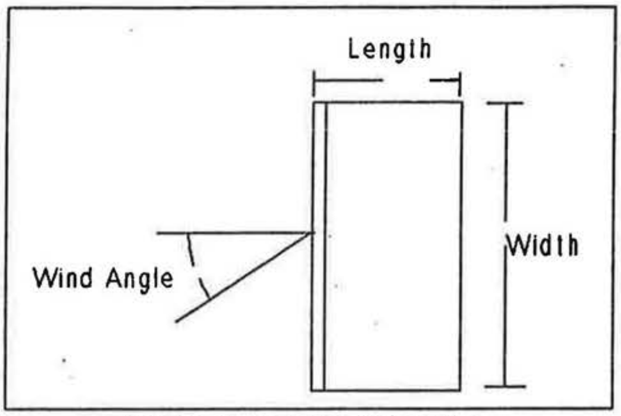


Figure 5: Building Orientation

Stack Pressures

The stack effect arises as a result of differences in temperature, and hence the air density, between the interior and exterior of a building. This produces an imbalance in the pressure gradients of the internal and external air masses, thus creating a vertical pressure difference. When the internal air temperature is higher than that of the outside air mass, air enters through openings in the lower part of the building and escapes through openings at a higher level. The level at which the transition between inflow and outflow occurs is defined as the neutral pressure plane (NPP). The stack pressure is expressed relative to the level of the lowest opening or a convenient datum, for example ground level.

In high-rise buildings, the significance of the stack effect must be considered for a number of configurations. These are:

- building with isolated floors,
- building with semi-isolated floors,
- uniform internal temperature distribution, and
- non-uniform internal temperature distribution.

The high-rise residential building is generally treated as a building with isolated floors with uniform internal temperature. The pressure difference due to stack effect at height h2, with respect to the pressure at h1 is:

$$P_s=\rho g(h1-h2)[T_i-T_o]/T_o \tag{9}$$

where,

P_s	=	pressure difference due to stack effect, Pa
ρ	=	air density, kg/m^3 (about 1.2 at an average of indoor and outdoor temperature)
T_i	=	indoor temperature, K
T_o	=	outdoor temperature, K
h	=	building height, m

The pressure difference induced by the stack effect is roughly estimated as 0.04 Pa/(K.m). Therefore, in a 30 storey building with a 90 m height, an NPP assumed at one-half the building height, and an indoor/outdoor temperature difference of 30 K, the stack pressure will be approximately 54 Pa (90/2 m * 30 K * 0.04 Pa/(mK)).

The above equation provides a <u>maximum</u> stack pressure difference, given no internal airflow resistance. However, real multistorey buildings are neither completely open from inside nor airtight between the floors. Vertical air passages, stairwells, elevators, and other service shafts allow airflow between floors. The ratio of stack pressure of a building to the stack pressure derived from theoretical calculations (considering no internal airflow resistance) is termed as *thermal draft coefficient*. The corrected local stack pressure can be calculated as

$$P_{sf}=P_s*ThermalDraftCoefficient$$

The location of NPP at zero wind speed depends on the vertical distribution of openings in the building envelope, the resistance of the openings to airflow, and the resistance to vertical airflow within the building. Internal partitions, stairwells, elevator shafts, utility ducts, vents, and mechanical supply and exhaust systems should be considered in estimating the local stack pressure. Maintaining airtightness between floors and from floors to vertical shafts is a means of controlling indoor-outdoor pressure differences, and therefore infiltration.

Table 5: Suggested Thermal Draft Coefficient [ASHRAE 1989 and AIVC 1982]

	Thermal Draft Coefficient
Building with isolated and sealed floors (tight)	0.6 to 0.7
Building with semi-isolated floors (average)	0.7 to 0.85
Building with poorly isolated floors and several through shafts (loose)	0.86 to 0.95
High-rise residential building with 2 elevator shafts, 2 stairways, garbage and service shafts	0.80 to 0.90

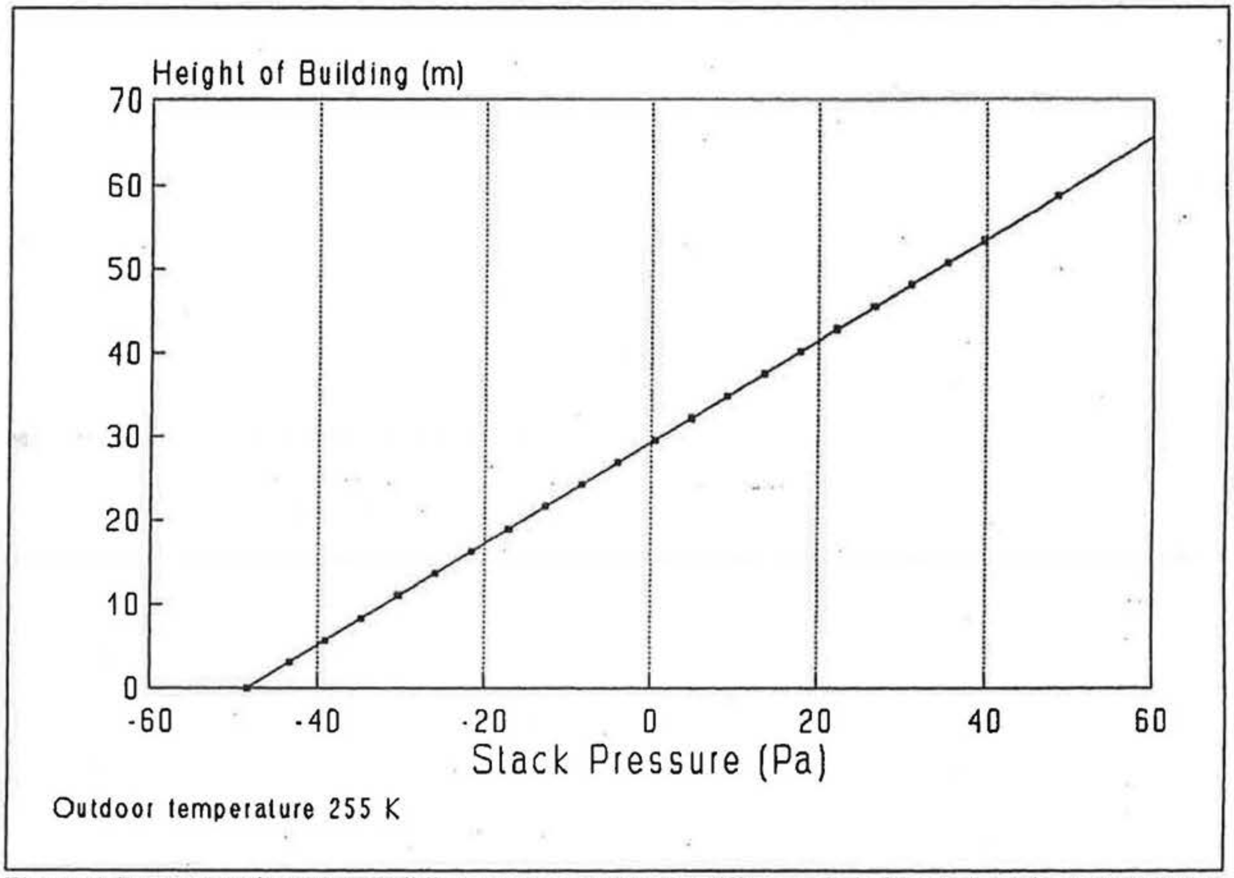


Figure 6: Pressure acting across building envelope due to the difference in indoor and outdoor temperature (ideal).

Mechanical Ventilation

The effect of mechanical ventilation on envelope pressure differences depends on the direction of the ventilation flow (exhaust or supply) and differences in these ventilation flows among the zones of the building. If mechanically supplied "conditioned" air is provided uniformly to each storey, the change in the exterior wall pressure difference pattern from stack pressures is uniform. With a non-uniform supply of outdoor air (for example, to one storey only), the extent of pressurization varies from storey to storey and depends on the internal airflow resistance.

The mechanical ventilation in most high-rise buildings is designed to provide uniform fresh air flow to each floor. Mechanical ventilation may exert a constant pressure of 0.5 to 4 Pa depending on the airtightness of the building shell. The ground level may be generally pressurized more than the other floors to reduce the stack pressure across entry doors.

2.1.3 Combined Infiltration Driving Forces

The wind, stack and mechanical pressure differences are summed to obtain a total pressure at each opening. Because the airflow rate through envelope openings is not linearly related to pressure difference, the resulting individual pressure differences should be combined by algebraic sum, as opposed to adding the airflow rates due to separate driving forces. The combined pressure at any height h is given as:

$$P_h = P_{w_h} + P_{s_h} + P_{vent} \quad (11)$$

The relative importance of the wind and stack pressures in a building depends on building height, internal resistance to vertical airflow, local terrain, and shielding of the building. The taller the building and the lesser the internal resistance to airflow, the stronger the stack effect. The more exposed a building, the more susceptible it will be to wind.

Another model to compute the total airflow rate is based on the rate being proportional to the square root of the pressure difference. The separate stack and wind components of air infiltration values are added in quadrature to obtain the total infiltration rate due to combined wind and stack pressures.

$$Q_{ws} = (Q_w^2 + Q_s^2)^{1/2} \quad (12)$$

where,

Q_{ws} = total air infiltration, L/s
Q_w = infiltration due to wind, L/s
Q_s = infiltration due to stack, L/s

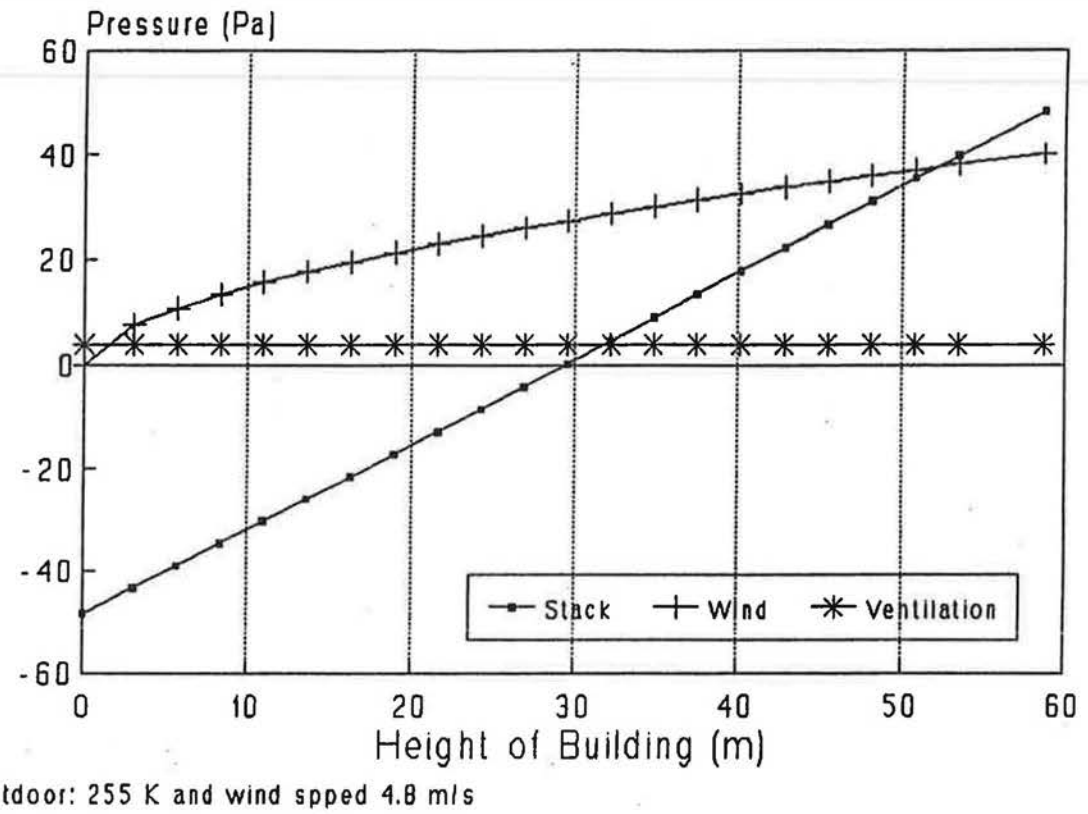


Figure 7: Wind, Stack and Ventilation Pressure Distribution.

Using computer-model studies of multistorey office buildings, the combined wind and stack flows were related using the following empirical equation [Shaw 1977]:

$$\frac{Q_{ws}}{Q_{lrg}} = 1 + 0.24\left[\frac{Q_{sml}}{Q_{lrg}}\right]^{3.3} \tag{13}$$

where,

Q_{lrg} is larger value of Q_w and Q_s

Q_{sml} is smaller value of Q_w and Q_s

Q_{ws} is shown to be 24% greater than either Q_w or Q_s, when $Q_w = Q_s$. The quadrature Equation (12) may be compared with the value of 41%. As shown in Figure 9, equation (12) gives an estimate maximum of 14% larger than Equation (13). In most practical cases the ratio of Q_{sml}/Q_{lrg} varies from 0.4 to 0.6; at these values the combined flow estimation from the above two methods differs by less than 6%. In the present work, the

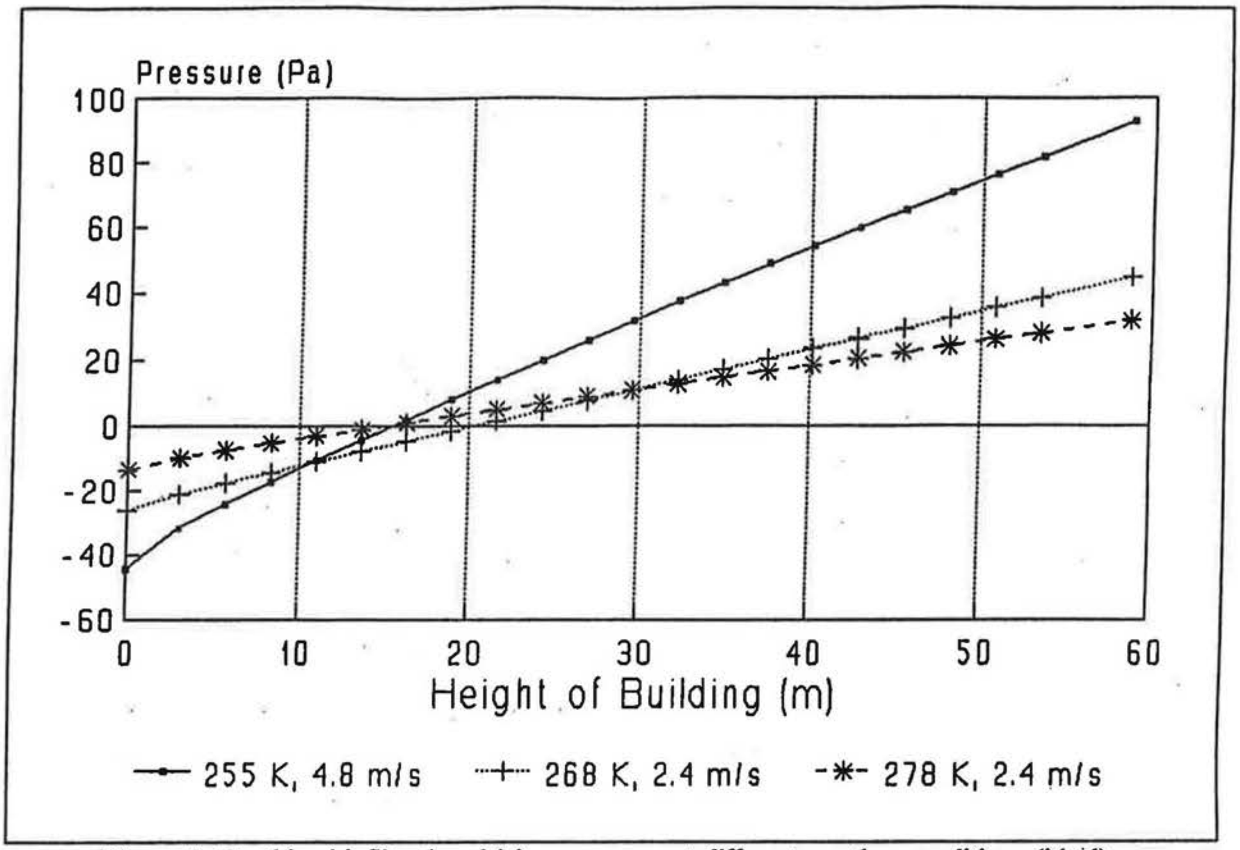


Figure 8: Combined infiltration driving pressures at different weather conditions (ideal).

quadrature method has been used. Figure 9 shows the typical air-flows due to stack Q_s, and wind Q_w, effects and the combined air-flows Q_{ws}, in a typical 22- storey high-rise residential building.

2.1.4 Relative Effects of Wind, Stack and Mechanical Ventilation on Air Leakage Rate

Stack effect for a building 60 m high and operating at a 35 K temperature difference with a thermal draft coefficient of 0.8 will be about 34 Pa. This pressure difference will be effective in producing infiltration on all sides of the building at ground level, and exfiltration at the roof decreasing with height to zero at the neutral pressure level (approximately half-height of the building); substantial pressure differences will be maintained over much of the heating season. The corresponding wind pressures for a location such as Ottawa are variable with time. The average wind speed is about 6.67 m/s, producing a pressure of about 12 Pa at 60 m at an urban site. A balanced mechanical ventilation system maintains a constant pressure difference of 1 to 4 Pa across the building envelope depending on the airtightness. The air-flow rates due to stack, wind and mechanical ventilation depend on these driving forces. For a 60 m high residential building located at an urban site in Ottawa, during peak winter conditions (35 K temperature difference and 6.67 m/s wind), the air leakage rate due to stack effect will be roughly 0.45 $l/s.m^2$, wind effect will be 0.15 $l/s.m^2$ and mechanical ventilation flow rate will be roughly 0.35 $l/s.m^2$ of floor space. The combined effect of these flows will produce an air leakage component of 0.58 $l/s.m^2$ of floor space.

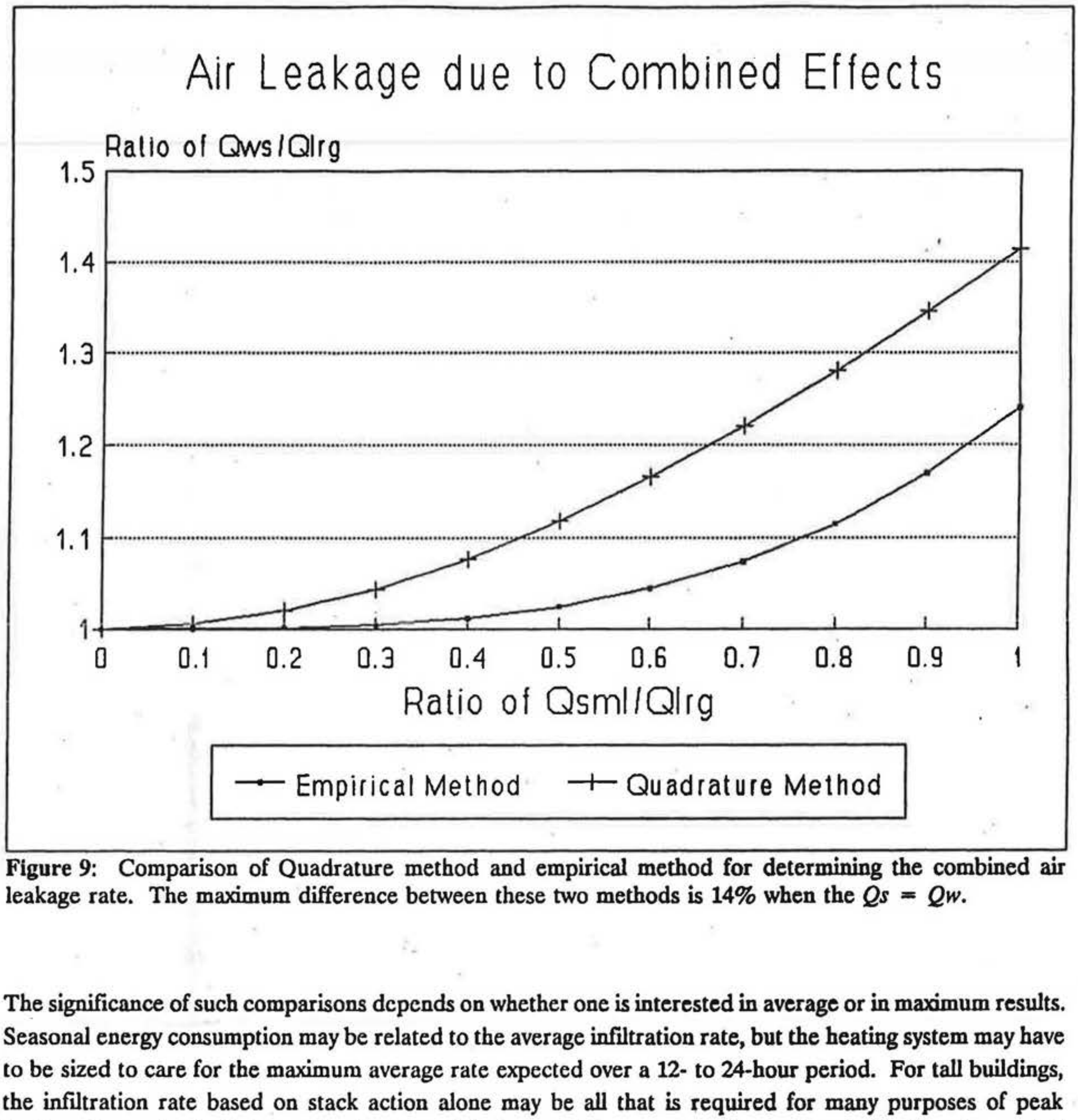


Figure 9: Comparison of Quadrature method and empirical method for determining the combined air leakage rate. The maximum difference between these two methods is 14% when the $Qs = Qw$.

The significance of such comparisons depends on whether one is interested in average or in maximum results. Seasonal energy consumption may be related to the average infiltration rate, but the heating system may have to be sized to care for the maximum average rate expected over a 12- to 24-hour period. For tall buildings, the infiltration rate based on stack action alone may be all that is required for many purposes of peak heating demand calculation, and of course, it is less troublesome to estimate than infiltration from wind action. As a peak demand reduction strategy, one should evaluate the maximum average leakage rate expected over a 12- to 24-hour period.

2.1.5 Air Leakage through Building Enclosures

The airtightness or the air leakage distribution in high-rise buildings can be assessed in two ways:

- by the whole building airtightness test using a calibrated fan,

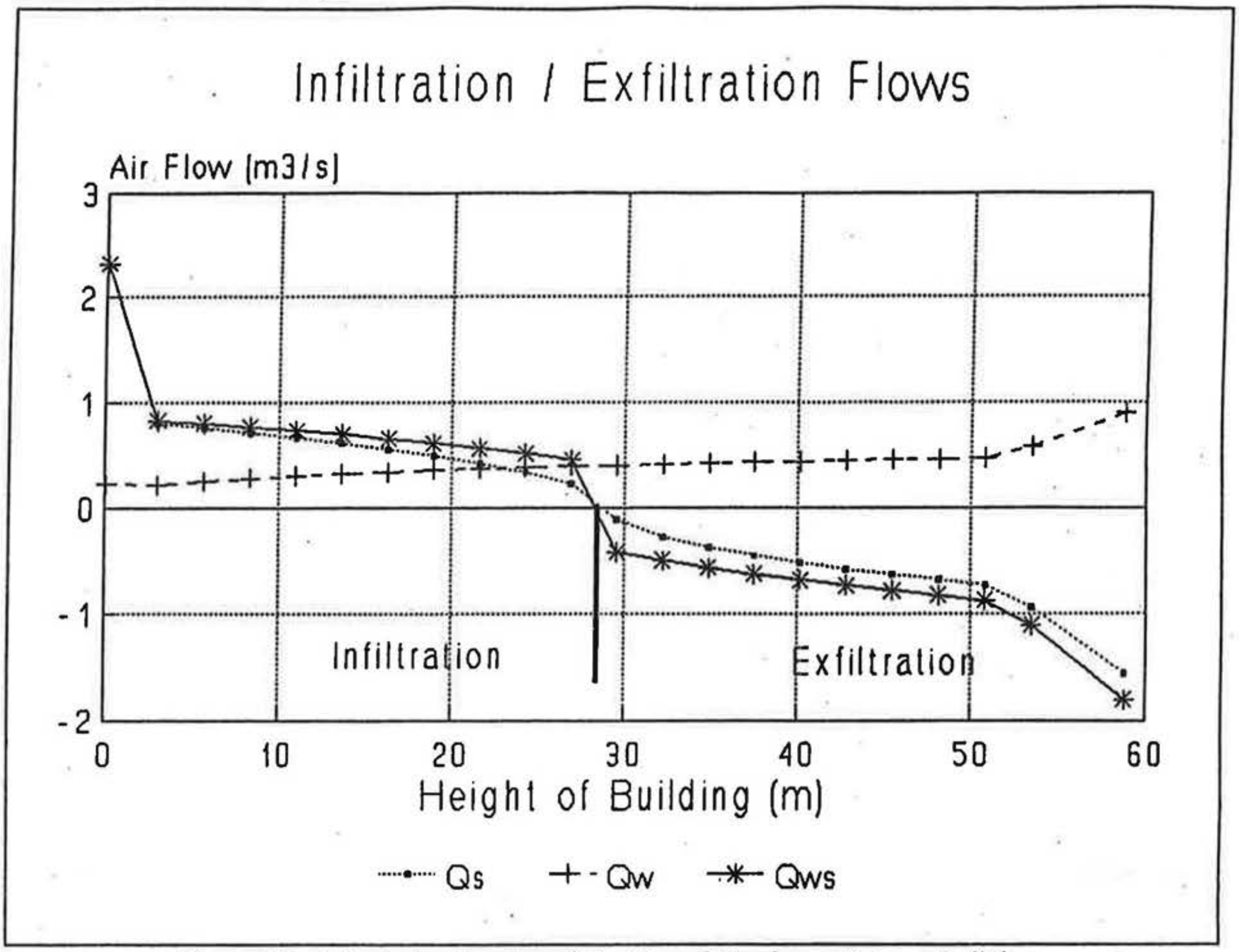


Figure 10: A typical estimation of Q_s, Q_w and Q_{ws} for a 20 storey building.

- the qualitative assessment of air leakage paths and characteristics using visual inspection, thermography, smoke-pencils, draft meters and suite depressurization.

The whole building airtightness test using a large axial fan(s) is the more accurate and reliable method for determining the air leakage characteristics of the building envelope. The literature review shows that this method has been extensively developed and practised in the field for research purposes. Field tests were conducted for developing the knowledge base and understanding air infiltration and exfiltration in high-rise buildings. A large axial fan of 24 m^3/s (50,000 CFM) capacity is used to depressurize the building. The airtightness is determined using the test method as described in the CMHC 1990 report "*Establishing the protocol for measuring air leakage and air flow patterns in high-rise buildings*". The fan test requires specific weather conditions: an indoor/outdoor temperature difference of less than 10 C, and wind speed lower than 5.6 m/s (20 km/h).

Such whole-building fan testing is too costly for general commercial applications due to the need for: (i) full access to all suites (apartments) in the building, (ii) favourable weather conditions, and (iii) skilled rigging and operation of the fan and many accessories. Nevertheless the whole building test is both a definitive research tool and a verification or quality control tool for sampling checks on commercial work.

The qualitative visual assessment method is not definitive, but it is potentially much less costly and more broadly useful for commercial application to much of the high rise building stock. The air infiltration or exfiltration flows in the building can be estimated by evaluating various leakage paths in the building. The leakage distribution in buildings is a function of the style of construction which, in turn, is a response to the climatic conditions, the prevailing architectural fashion, and the building code requirements at the time of construction. The leakage distribution, being largely accidental, differs substantially in each building. The amount of the building's leakage which cannot be attributed to components such as windows, doors and shafts (also known as background leakage) depends to a degree on prevailing construction practises.

One of the objectives of this project is to identify the relative air leakage importance of different components of the building. Such a ranking of air leakage through different components would assist in a cost effective selection of air sealing priorities which would result in a maximum reduction in peak heating demands (i,e. to obtain high ratio of kW saved to the cost of air sealing). The building components are divided into five different groups:

1. Windows: In most high-rise buildings, windows account for 15 to 35% of the total perimeter wall area. Air leaks through the perimeter of operable window, and window sashes and glazing units contribute substantially to uncontrolled air infiltration. The wall and window junction is also a prime source of air leakage. The Window Standard CSA-A440 grades the windows according to the classifications shown in Table 6.

   The operable windows exert wear and tear on weatherstripping and sliding rails which increases the air leakage drastically. As an example, a double slider window installed in the Bridleview building (with an original A2 classification) showed air leakages almost three times higher when tested at 75 Pa. The window leakage differs widely among different types. Windows that seal by compressing the weatherstrip (casements, awnings) have significantly lower leakage than windows with sliding seals. For implementing air leakage control measures, windows which show characteristics of average or loose should be considered. Windows which are air "tight" should not be considered for retrofit measures. Table 6 can be a guide in determining the tightness classification.

Table 6: Air leakage classification as per Window Standard CSA-A440

Window Rating	Maximum air leakage rate per unit of crack length at 75 Pa $m^3/hr/m$	Leakage Rate at 4 Pa. $m^3/hr/m$
A1	2.79	0.36
A2	1.65	0.21
A3	0.55	0.07
Fixed	0.25	0.03
Storm	5.00 to 8.35	0.64 to 1.1

If the windows exhibit airtightness characteristics similar to their original design condition, windows need no weatherstripping or caulking. If the air leakage characteristics show deterioration in the air-sealing, windows should be considered for weatherstripping. The airtightness is classified in three distinct groups: tight, average and loose. "Tight" signifies the near perfect seal between the sliding elements. If the window sliding pane is easily sliding and exhibits "smoke" deflection, the window is considered as an "average" air leaky. Weatherstripping of such windows will result in improving the airtightness. Of course, the "loose" condition may be observed when the sliding panes are loose, and there is substantial air leakage through the perimeter of a window. These windows should be considered for weatherstripping and/or caulking. Schelegal window testing equipment is recommended to conduct in-situ window airtightness tests.

2. External Doors: In most high-rise buildings, either wooden doors or glass patio doors account for 6 to 12% of the total perimeter wall area. Air leaks through the perimeter of operable doors and the door frame and glazing unit contribute to uncontrolled air infiltration. The wall and door junction is also a source of air leakage.

   The doors exert wear and tear on weatherstripping and sliding rails which increases the air leakage drastically.

3. Building Envelope: Building component junctions contribute to air infiltration. These are:

   - basement and first floor junction,
   - perimeter wall and floor interface for the bottom and top zones of the building,
   - roof and wall gap,
   - baseboard heater wiring where it penetrates wall and floor zones,
   - the partition-into-wall junctions,
   - the wall and window or door junctions,
   - interior partitions provide pathways into each floor space and to exterior wall space,
   - exterior light fixtures,
   - basement walls and slab floor junctions, and
   - plumbing and piping holes.

4. Elevator Shafts and Service Shafts: In high-rise buildings, elevators, stairwells, service shafts and vertical plumbing or electrical stacks comprise a significant part of the total air leakage. These components allow free air flow patterns due to stack effect. It has been shown that sealing or isolation of these shafts reduces the air leakage in the building by 10 to 25%. The air sealing can be done around cables and chain drives, the perimeter of the penthouse, stairwells, fire doors, penthouse at roof and garbage chute hatches.

5. Miscellaneous

There are other smaller components in the building which contribute to air leakage. If these components are not properly sealed, they may contribute to a large proportion of air leakage in the

building. These components are:
- backdraft dampers on suite exhaust fans
- ducting for suite exhaust fans behind grills
- inspection hatches
- laundry chute exit
- ducting for exhaust fans in kitchen and bathrooms

Table 7 provides the effective crack width for different building components for three categories of buildings. These crack widths are suggested values for the air-sealing practitioners.

The field inspection of various air leakage paths involve the following steps:

- Examining the air leakage paths: Any crack or opening in the building envelope which allows the transfer of outdoor air to indoor, or indoor air to outdoor, is considered as a clear air leakage path. The air leakage path may be a straight forward or through a torturous windings. It is essential that during the field visit, assessor should be able to identify air leakage paths through visual inspection and/or with simple in-situ tests.

- Determining size of air leakage path: Once the air leakage path is located, assessor should measure the size of this air leakage path. For envelope cracks or window and door perimeter leaks, length of such paths can be measured. Elevator shafts, garbage chutes, service shaft opening leading to outdoor can be measured.

- Determining the class of air leakage: The severity of air leakage is classified in to three groups: tight, average and loose. Visual inspection, smoke pencilling, suite fan depressurization tests, in-situ window tests assists in determining the class of air leakage. The relative significance of air leakage classification is important. If the air leakage path is classified as "tight", there is no need to implement air sealing of that component. "Average" and "loose" signifies the need for considering the building component for air sealing. Table 7 shows the width of building envelope air leak paths.

The air leakage area is thus determined using the size and classification of air leakage path. Field inspection should include complete building envelope and roof. Appendix B shows the field inspection report of a 21 storey multi-residential building. The details of field inspection are vigorously covered in the air leakage assessment procedure presented in the following sections.

Table 7: Effective Crack Width for Different Building Components (Derived from various sources listed in the references.) Dimensions in metres are more appropriate. Conversion to inches is approximate.

	Tight		Average		Loose	
	m	in	m	in	m	in
SILL FOUNDATION - WALL						
Caulked, per meter of perimeter	0.0002	1/128	0.0003	1/96	0.0004	1/64
Not caulked, per meter of perimeter	0.0004	1/64	0.0005	1/48	0.0008	1/32
JOINTS BETWEEN CEILING AND WALLS (if there is no vapour barrier)	0.0002	1/128	0.0003	1/96	0.0004	1/64
WINDOWS (per metre of window perimeter)						
Casement						
Weatherstripped	0.00013	1/192	0.0003	1/96	0.0005	1/48
Not weatherstripped	0.0002	1/128	0.0005	1/48	0.0008	1/32
Awning						
Weatherstripped	0.00015	1/160	0.0003	1/96	0.0005	1/48
Not weatherstripped	0.0002	1/128	0.0005	1/48	0.0008	1/32
Single Hung						
Weatherstripped	0.0003	1/96	0.0005	1/48	0.0008	1/32
Not weatherstripped	0.0005	1/48	0.0008	1/32	0.001	1/24
Double Hung						
Weatherstripped	0.0003	1/96	0.0008	1/32	0.0008	1/32
Not weatherstripped	0.0007	1/32	0.001	1/24	0.001	1/24
Single Slider						
Weatherstripped	0.0003	1/96	0.0008	1/32	0.001	1/24
Not weatherstripped	0.0007	1/32	0.001	1/24	0.0012	1/20
Double Slider						
Weatherstripped	0.0005	1/48	0.0008	1/32	0.001	1/24
Not weatherstripped	0.0007	1/32	0.001	1/24	0.0015	1/16
DOORS (per metre of door perimeter)						
Single Door						
Weatherstripped	0.0004	1/64	0.0007	1/32	0.0012	1/20
Not weatherstripped	0.0007	1/32	0.0012	1/20	0.0015	1/16
Double Door						
Weatherstripped	0.0003	1/96	0.0007	1/32	0.0012	1/20
Not weatherstripped	0.0007	1/32	0.0015	1/16	0.0015	1/16

	Tight		Average		Loose	
	m	in	m	in	m	in
WALL & WINDOW FRAME						
Wood Frame Wall, per metre of window perimeter)						
Caulked	0.0001	1/256	0.00013	1/192	0.00016	1/160
Partial or no caulking	0.0002	1/128	0.00025	1/100	0.0003	1/84
Masonry wall, per metre of window perimeter)						
Caulked	0.0004	1/64	0.0006	1/48	0.001	1/24
Partial or no caulking	0.0006	1/48	0.0008	1/32	0.0015	1/16
WALL & DOOR FRAME						
Wood Frame Wall, per metre of door perimeter)						
Caulked	0.0001	1/256	0.00013	1/192	0.00016	1/160
Partial or no caulking	0.0002	1/128	0.00025	1/100	0.0003	1/84
Masonry wall, per metre of door perimeter)						
Caulked	0.0004	1/64	0.0006	1/48	0.001	1/24
Partial or no caulking	0.0006	1/48	0.0008	1/32	0.0015	1/16
WALL JOINTS						
Wall & floor joints, per metre of length	0.0002	1/128	0.0003	1/96	0.0004	1/64
End wall joints, per meter of length	0.0002	1/128	0.0003	1/96	0.0004	1/64
Wall and roof joint, per m of perimeter	0.0003	1/96	0.0004	1/64	0.0006	1/48
Basement wall and first floor joint	0.0003	1/96	0.0004	1/64	0.0006	1/48
Wall cracks, if draft is felt	0.0003	1/96	0.0004	1/64	0.0006	1/48
ELECTRIC OUTLETS AND LIGHT FIXTURES	(in m^2)	(in^2)	(m^2)	(in^2)	(m^2)	(in^2)
Electric outlets and switches						
Gasketed or caulked, m^2 per outlet	0	0	0.0002	0.3	0.0004	0.6
Not gasketed, m^2 per outlet	0.0001	0.2	0.0004	0.6	0.0008	1.24
Recessed light fixtures						
Gasketed or caulked, m^2 per outlet	0	0	0.0004	0.6	0.0008	1.24
Not gasketed, m^2 per outlet	0.0015	2.33	0.002	3.1	0.0035	5.5

	Tight		Average		Loose	
	m	in	m	in	m	in
PIPE AND DUCT PENETRATION THROUGH ENVELOPE	(m^2)	(in^2)	(m^2)	(in^2)	(m^2)	(in^2)
Pipes						
Caulked or sealed, m^2 per pipe	0	0	0.0001	0.16	0.0002	0.31
Partially sealed, m^2 per pipe	0.0002	0.3	0.0006	1	0.001	1.6
Ducts						
Caulked or sealed, m^2 per duct	0	0	0.00016	0.25	0.0002	0.31
Partially sealed, m^2 per duct	0.0014	2.1	0.0024	3.72	0.0024	3.72
EXHAUST FANS	(m^2)	(in^2)	(m^2)	(in^2)	(m^2)	(in^2)
Kitchen Fan, m^2 per fan	0.0024	3.7	0.0030	5	0.0036	5.6
Bathroom Fan, m^2 per fan	0.0005	0.8	0.001	1.6	0.002	3.1
Dryer vent, m^2 per vent	0	0	0.0003	0.5	0.0006	1
ELEVATOR SHAFTS	(m^2)		(m^2)		(m^2)	
Walls, per m^2 of exterior wall covering elevator shafts (Leakage area/wall area)	0.00002		0.00003		0.00007	
Openings of elevator shafts to exterior, m^2 as found						
WINDOW AIR CONDITIONER m^2 per unit installed	0	0	0.0024 m^2	3.7 in^2	0.0036 m^2	5.6 in^2

2.1.6 Determination of Airflow at Each Storey

As shown in the previous sections, the theoretical model for air leakage is based on the network method which include the following parameters:

- flow path distribution and characteristics,
- building dimensions, exposure and orientation,
- inside / outside temperature difference,
- local wind speed and external pressure distribution, and
- characteristics of mechanical ventilation system.

The airflow rate through an opening area A is:

$$Q = C_d A \sqrt{(2 \Delta P / \rho)} \qquad (14)$$

where, Q = Airflow rate, m^3/s
C_d = discharge coefficient for the opening, varies from 0.65 to 0.85
A = leakage area, m^2
ρ = air density, kg/m^3
ΔP = pressure difference across building envelope, Pa

The leakage paths on the exterior building envelope and shafts are classified as following:

- the basement floor plus ground floor [A_G],
- typical floor [A_T], and
- top floor and penthouse [A_R].

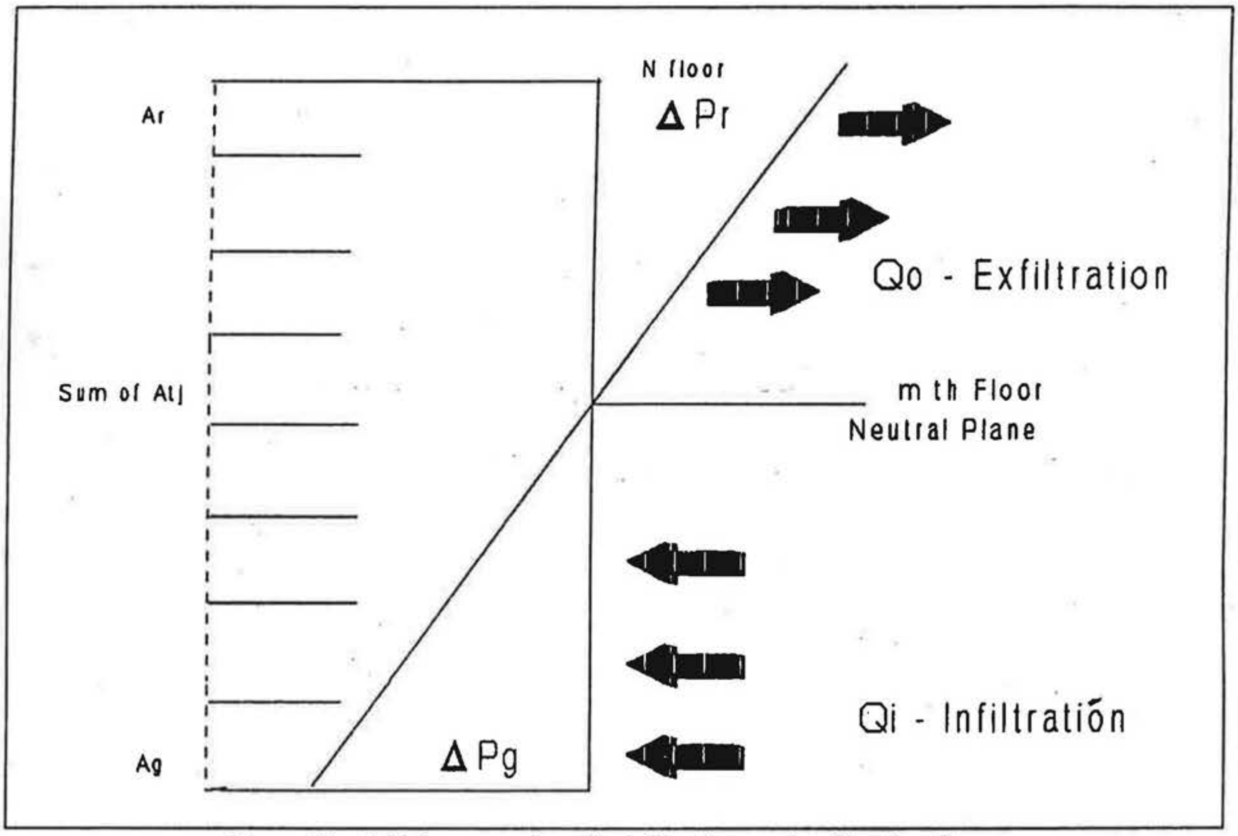


Figure 11: Initial assumptions for infiltration and exfiltration flows.

Assuming that there is a neutral zone at the m[th] floor as shown in Figure 11, the infiltration rate Q_i and exfiltration rate Q_o through the exterior wall can be expressed as the following with the inner/outer pressure differential ΔP (Pa) and leakage area A (m^2):

$$Q_i = A_G\sqrt{(2|\Delta P_G|/\rho)} + \sum_{j=2}^{M-1} A_{Tj}\sqrt{2|\Delta P_j|/\rho)} \quad (15)$$

and

$$Q_o = \sum_{j=M}^{N} A_{Tj}\sqrt{2|\Delta P_j|/\rho)} + A_R\sqrt{(2|\Delta P_R|/\rho)} \quad (16)$$

The airflow balance is

$$Q_i = Q_o \quad (17)$$

The solution to the above three equations can be obtained using the following steps:

1. Determine the leakage paths and leakage areas at each floor (visual inspection, building audit, assign leakage area...).

2. Establish the stack pressure and wind pressure distribution and determine the net indoor/outdoor pressure difference at each floor.

3. Calculate the air flows at each floor level using the above equations by assuming first that the neutral pressure plane occurs at the mid height of the building.

4. Equate the air inflow and outflow ($Q_i = Q_o$). If inflow is greater than outflow, then move the NPL one floor below and repeat the calculations as in Step 3. If the inflow is lower than the outflow, then assume the NPL one floor above and repeat the calculations. These steps should be repeated until a five percent difference (ideally less than one percent) between inflow (Q_i) and outflow (Q_o) is obtained.

5. The air flow rate, Q_i or Q_o, to the building is the uncontrolled air leakage. Reduction in this component will result in reducing the peak heating demand and energy consumption.

2.1.7 Calculation of Peak Heating Demand due to Infiltration

The load associated with air infiltration can be calculated from the infiltration and the enthalpy difference between inside and outside. The infiltration load can be treated in a manner analogous to that used for conductance loads; specifically, equivalent infiltration conductances can be determined. Using the infiltration flow rate, peak heating due to infiltration at the design weather conditions can be expressed as follows:

$$q=Q_i \rho C_p \Delta T \tag{18}$$

where,

- q = heating load due to air infiltration, W
- Q_i = air inflow rate, L/s
- ρ = air density, kg/m^3 (about 1.2)
- C_p = specific heat of air, kJ/(kg C) (about 1.0)

Using standard air ρ = 1.2 kg/m^3, and C_p = 1.0 kJ/(kg C), the above equation simplifies to:

$$q=1.2Q_i(T_b-T_o) \tag{19}$$

$$T_b=T_i-\frac{q_{internal}}{UA} \tag{20}$$

where, T_b is the balance point temperature used for infiltration calculation. It depends on the thermostat set temperature, conductance heat losses through the building envelope (excluding infiltration losses), and internal loads ($q_{internal}$) due to lighting, occupancy and other equipment. T_i is the thermostat set temperature and T_o is the exterior temperature.

UA is the combined transmission and ventilation loss, W/K per m^2 of floor area.

$q_{internal}$ is the internal heat gain from lights, people, equipment and solar, W per m^2 of floor area

The UA varies from 0.75 to 1.1 W/K per m^2 of floor space (assuming wall insulation level RSI 2.5, windows with RSI 0.35, roof insulation of RSI 3.5 and an indoor/outdoor temperature difference of 35 K) in high-rise residential buildings. The $q_{internal}$ varies from 10 to 15 W/m^2. Assuming UA = 1 $W/K/m^2$ and $q_{internal}$ = 12 W/m^2 and T_i = 20 C (293 K), the balance point temperature would be, T_b = 8 C.

The above heating load is the total demand due to uncontrolled infiltration. The air-sealing of the building has a maximum potential to reduce the peak heating demand by this amount. It is almost impossible to reduce the air infiltration value to zero. Proper and cost effective air-sealing will result in reducing a portion of air infiltration. The reduction in heat load will be in proportion to the air-sealing effectiveness.

For most high-rise residential buildings the air-sealing effectiveness may vary from 25% to a maximum of 40% depending on the extent of air sealing. It is safe to assume the one-forth to one-third rule in determining the effectiveness ($S_{effectiveness}$) of air sealing.

The reduction in peak heating demand due to air sealing will then be:

$$HL_{infiltration(reduction)}=S_{effectiveness}*q \tag{21}$$

The $HL_{infiltration\ (reduction)}$ should be utilized in determining the incentive for air-sealing costs.

Calculation of the energy requirements for heating buildings can be carried out in various ways with varying accuracy. The most common methods are:

- Degree-day method
- BIN method
- Calculation of Heat Loss Method

For simplicity, the degree day method is used here to determine the approximate reduction in annual space heating energy requirements. The reduction in energy consumption is given as the following:

$$E=(HL_{infiltration(reduction)}*DD*C)/(\Delta T) \tag{22}$$

where,

E	= Annual reduction in space heating energy, kWh
DD	= Annual heating degree days, (C - days)
ΔT	= Design temperature difference, C (For Toronto, 38 C)
C	= C-factor, Credit factor, hours/day

The value of degree days is generally obtained from the weather data (as shown in Table 3). The C-factor allows credits for internal heat gains due to sun, lights, people, equipment, for night setback and for reduced mechanical ventilation. With these internal gains, only a fraction of the full load energy is actually required. This fraction, multiplied by 24 (hours/day) produces the "C" factor. For high-rise residential buildings, the C-factor varies from 14 to 18 hours/day [Ontario Hydro, 1988].

2.2 Development of Assessment Procedure

The procedure for air leakage assessment and control in buildings has been developed to meet the requirements of air-sealing practitioners (contractors) in estimating the potential reductions in energy and power, quantifying the air-sealing work and assessing the air-sealing priorities. Figure 12 shows the self-explanatory flow chart for this procedure. The air sealing assessment procedure (ASAP) would lead the practitioner through the various factors and steps:

1. Building inspection, audit of air leakage paths and data collection:

   climate and exposure, building types, building form, surface to volume ratios, shafts, and envelope types; floor by floor cracks, openings, weighting of air leaks, top and bottom floor priorities, building component characteristics; building operation; space heating fuels; building problems; indoor air-quality tests; and energy consumption bills of at least the last 12 months.

2. Estimation of air leakage component:

   Assign leakage paths; characterize wind and stack pressure distribution for peak weather conditions; calculate in and out air flows; and determine the air leakage component.

   Estimate the potential reductions in peak demand by various building components; air-sealing work cost estimates; and prioritize the potential air-sealing applications.

   Prepare a report describing the various sealing options and strategies and associated costs.

   Assessment of indoor air quality: Perform on the spot tests for air quality (with hand-held equipment) to assess the air movement, temperature stratification and humidity levels. With the estimates of the air-infiltration component and initial measurements of various air quality variables determine the impact of air-sealing (whether the air sealing would deteriorate, improve or maintain the existing air quality).

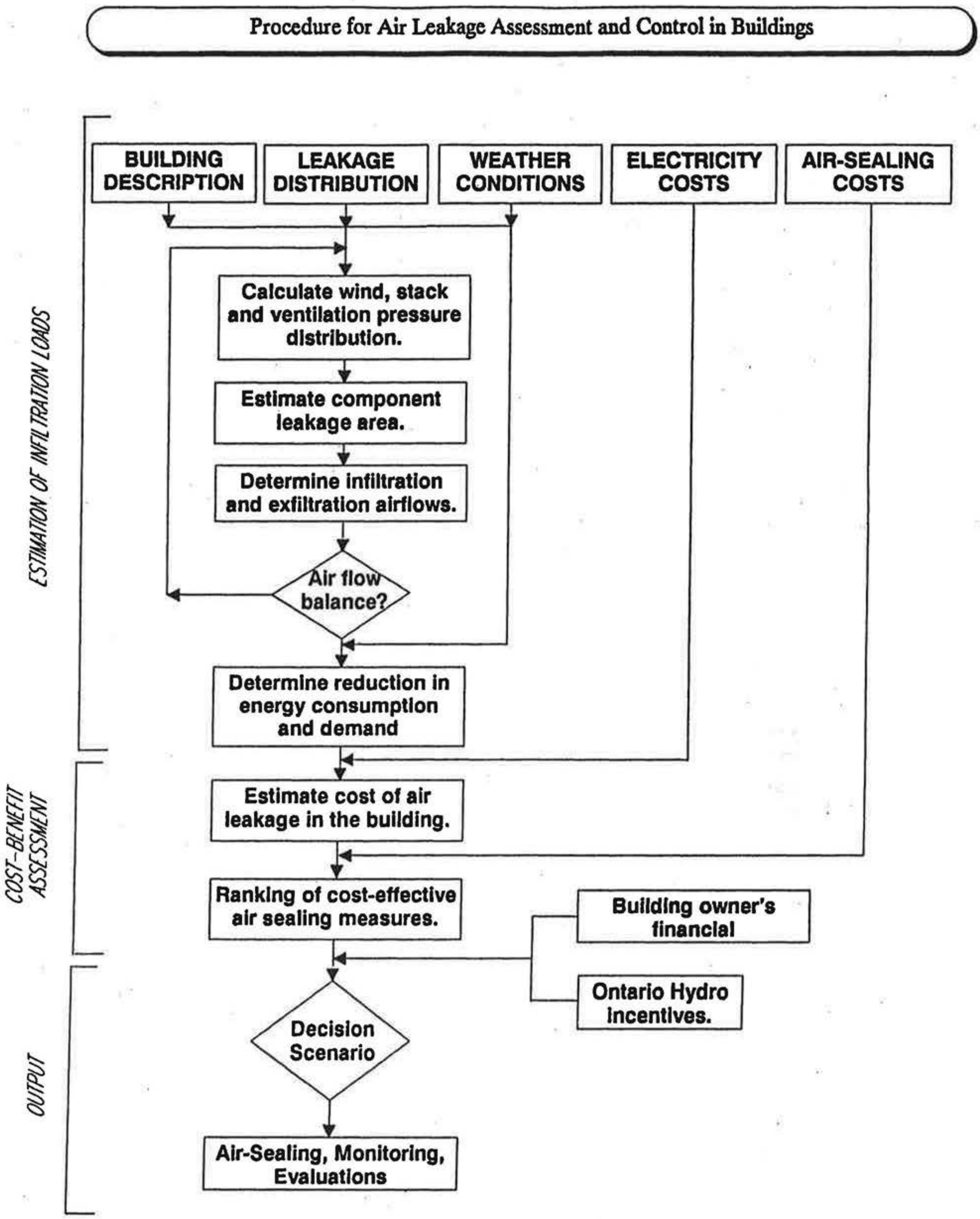
3. Assessment of cost-benefits and decisions regarding implementation of air-sealing.

The air-sealing assessment procedure (ASAP) for high-rise buildings has been assembled in the following parts:

- **Part A:** Building Audit and Field Inspection;
- **Part B:** Estimation of the Uncontrolled Air Leakage Component and Determination of Air Sealing Priorities; and
- **Part C:** Development of a Work Plan for Air Sealing of the Building.

Appendix A contains the procedure for assessing air leakage and potential control in electrically heated residential buildings of eight storeys and higher.

Figure 12: Procedure for Assessing Air Leakage And Potential Control in Buildings.



2.3 Summary

A simplified air infiltration estimation procedure has been developed primarily based on equivalent air leakage areas and local net pressure distributions. The pressure difference at a given location depends on the infiltration driving forces (stack, wind and mechanical ventilation) and the characteristics of the openings in the building envelope. A simplified network of air-flow paths can be established using the following information: climate and exposure, building types, building form, building dimensions, surface to volume ratios, shafts, and envelope types, windows and doors, envelope crack lengths, openings, and make-up air strategies. The algebraic sum of air-flow through these paths must always be equal to zero. By applying the mass balance equation, the component of air infiltration which would be occurring during the peak winter condition can be determined. This air-flow rate is responsible for the space heating load due to uncontrolled infiltration. Any reduction in this infiltration flow should decrease the heating requirements for the building. The procedure has been simplified and developed into a practical application tool which can be utilized by the assessors and air leakage control contractors.

3. FIELD DEMONSTRATION AND VALIDATION OF ASSESSMENT PROCEDURE

The main objectives of the field demonstration of air sealing work were:

- to verify the air sealing estimation procedure;
- to assess the practical implications of air sealing on the indoor air quality and thermal comfort; and
- to show the potential of air leakage control in reducing the peak power demand and energy consumption.

Two high-rise, electrically heated residential buildings were selected for evaluating the effects of air leakage control on: (1) reducing the peak power demand and energy consumption, (2) airtightness of the building, and (3) indoor air quality. The 251 Donald Street building, located in Ottawa, is a 21 storey, 61 m high building having approximately 14,500 m^2 heated space. It is an all-electric building. The 2500 Bridletowne Street (Bridleview York Condominium) building, located in Toronto, is 10 storeys, having approximately 9,800 m^2 heated space. In the Bridleview building, each suite is equipped with electric baseboard heaters; however, the make-up air supplied to corridors is heated with natural gas.

Field tests on the two high-rise buildings enabled the verification and tuning of the air sealing estimation procedure and guidelines as described in the previous sections. The field tests provided measured heat load and demand reduction data associated with measured airtightness improvements.

3.1 Building Description, Heating System and Energy Audit

3.1.1 Donald Street Building

The 251 Donald Street building is a 21-storey apartment tower operated for senior citizens and owned by the **Ottawa-Carleton Regional Housing Authority (OCRHA)**. Its 240 units are almost fully occupied. There are no other buildings within 50 metres and no other high structures in the surrounding residential neighbourhood. Parking space for 180 cars surrounds the building on three sides. The main entrance faces east. Photographs of this building are attached at the end of this chapter.

The building is comprised of single self-contained (bachelor), one bedroom and two bedroom apartments. There is a lobby, games and entertainment room, a billiards room and laundry facilities on the first floor. These facilities are normally open from 08:00 to 22:30 hours.

The construction is concrete flat plate, with no insulation at the floor perimeter; the floors extend to form balconies with no thermal break or protection. The walls are insulated with 38 mm extruded polystyrene insulation. The total floor area of heated space is 14,290 m^2 (153,760 ft^2) and the heated volume is 43,515 m^3 (1,537,600 ft^3). There are two elevator shafts and one garbage chute in the centre of the building, and two stairwells at ends.

The make-up air handling unit is located in the penthouse, supplying air at 6050 L/s (12,600 cfm) or 283 L/s per storey (600 cfm/storey). It is rated at 7.5 hp. The heating coil consists of a total 390 kW load connected to a 600 V, 3-phase supply. For temperature control, the heating coil has one stage of 50 kW and 10 stages of 34 kW elements. The control circuit ensures the heating elements will not be on unless the make-up air fan is running. The make-up air unit was not working during the months of November and December 1990. It was repaired and put into service on January 7, 1991. The make-up air unit is operated between 08:00 and 11:00 and between 16:00 to 20:00 hours. The make-up air supply to each floor was balanced and tuned after the air-sealing work.

The heating system in the top floor corridor contains a 8 foot (2.5 m) long baseboard heating element with a thermostat. A 1000 W baseboard heater, with an integral thermostat, is located on every 4th floor in each stairwell. In each suite, baseboard heating elements are located along the exterior walls. Each room is controlled with an individual thermostat. In the corner units, where the bathrooms also share an exposed wall, a small baseboard heater with an on-board thermostat is present. The heating system was modified previously to remove unnecessary baseboard elements. Exhaust fans are provided in the kitchen and bathroom; the latter is wired with the light switch.

In the entertainment area, located at the ground floor level, a separate air make-up unit provides the fresh air supply to this room and the games room. The make-up unit is controlled with a thermostat located in the games room.

The total installed capacity of the baseboard heating system is 1,268 kW and make-up air heating system of 390 kW. A detailed energy analysis showed that the peak heating demand was 575 kW in the year 1990. The *cycling factor* of the space heating system was approximately 0.35.

The transformer room is ventilated by a small make-up air unit which is maintained by Ontario Hydro.

Energy Audit

The total energy bill for 1989 was $141,670. With a transformer loss credit of $1,450, the bill payable by the client was $140,220, or $9.80/m^2/year (202.2 kWh/m^2/year).

An analysis of energy use was performed by examining the monthly electricity bills for a period of 24 months. A load and energy usage pattern was developed on the basis of various equipment sizes and rating information obtained through physical examination and manufacturer's information. Almost 98% of the annual energy consumption was accounted for in this analysis. Figure 13 shows the profile of heating degree days in Ottawa. Figure 14 shows the profile of base and space heating energy consumption.

The estimates of base consumptions include the following: lighting needs for suites, corridors, stairwells, exit signs, penthouse and outdoors; and energy requirements for the hot water system, suite appliances, suite fans, laundry, elevators and air-conditioners. The total consumption profile includes the base consumption and space heating requirements.

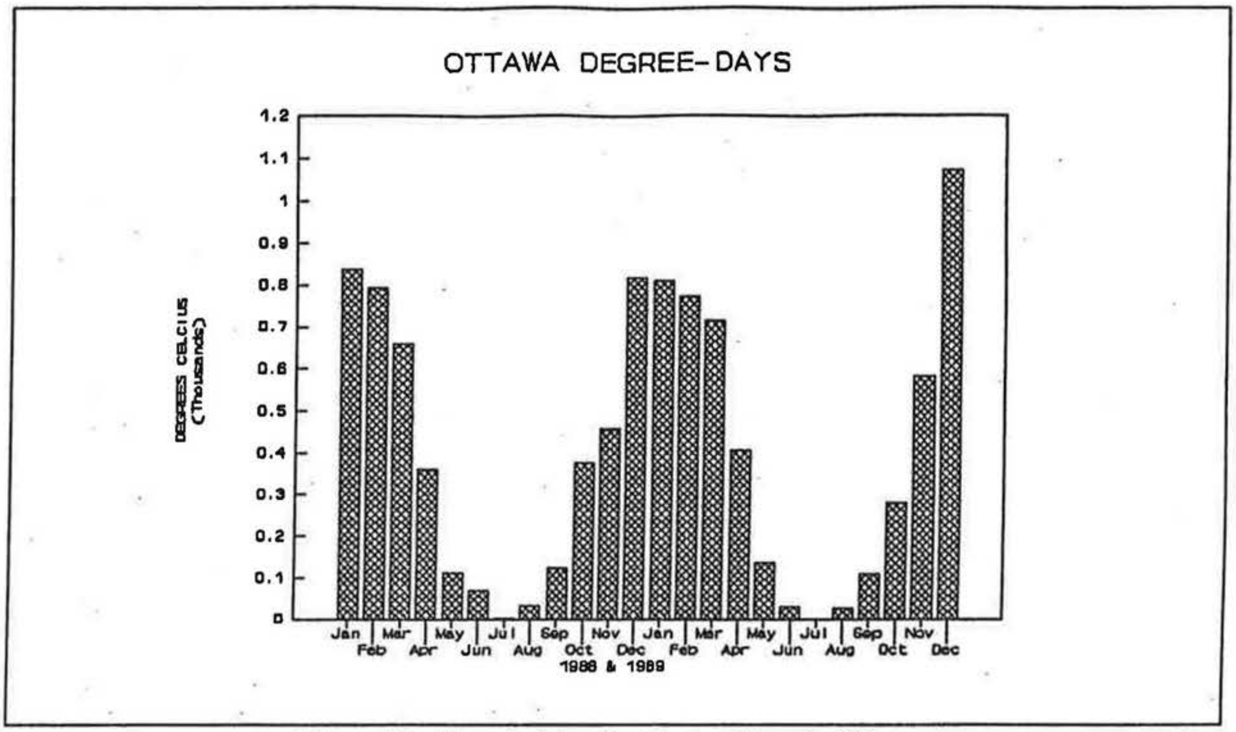


Figure 13: Measured heating Degree Days in Ottawa.

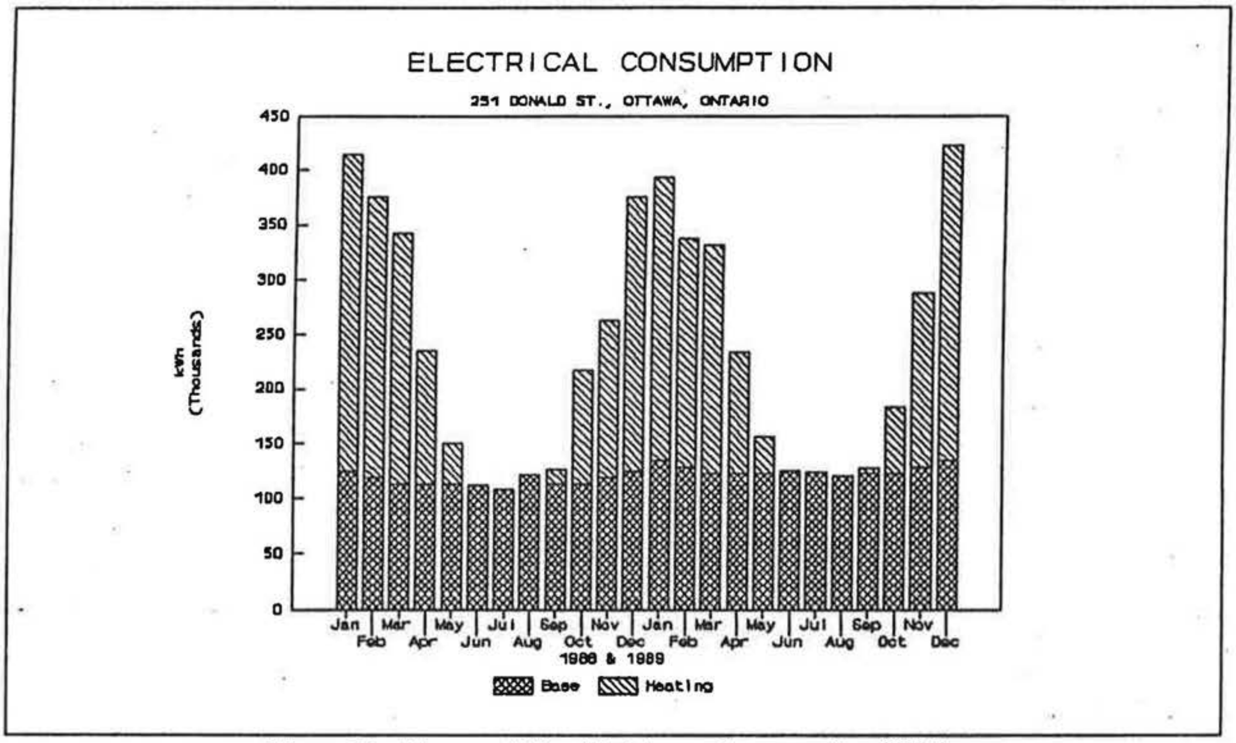


Figure 14: Measured Monthly Energy Consumption (kWh).

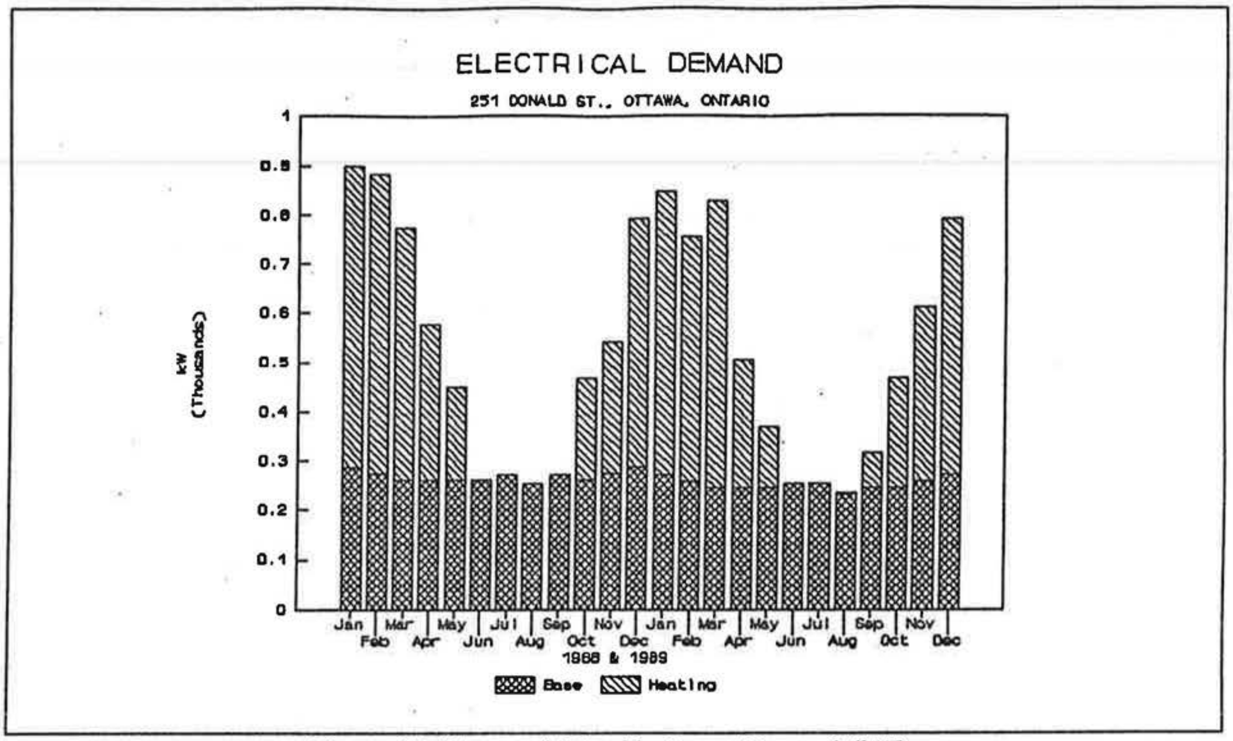


Figure 15: Measured Monthly Power Demand (kW).

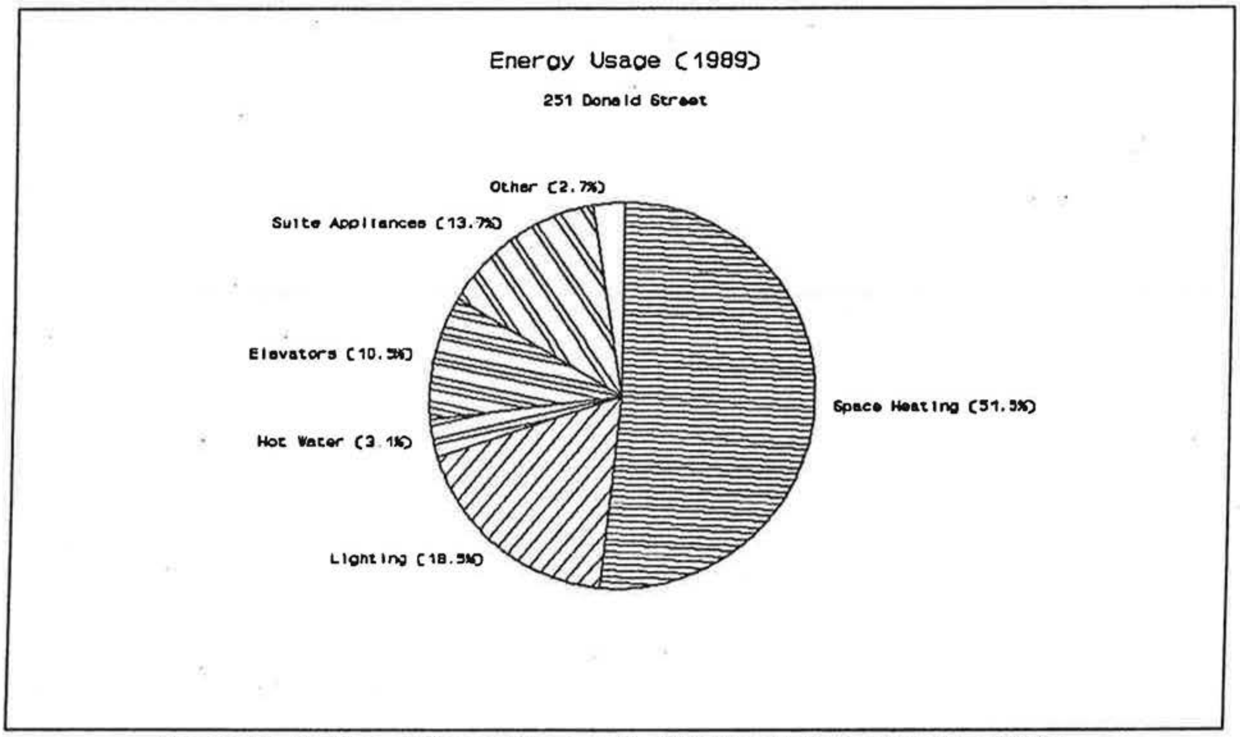


Figure 16: Analysis of Energy Usage in the 251 Donald Street Building (1989).

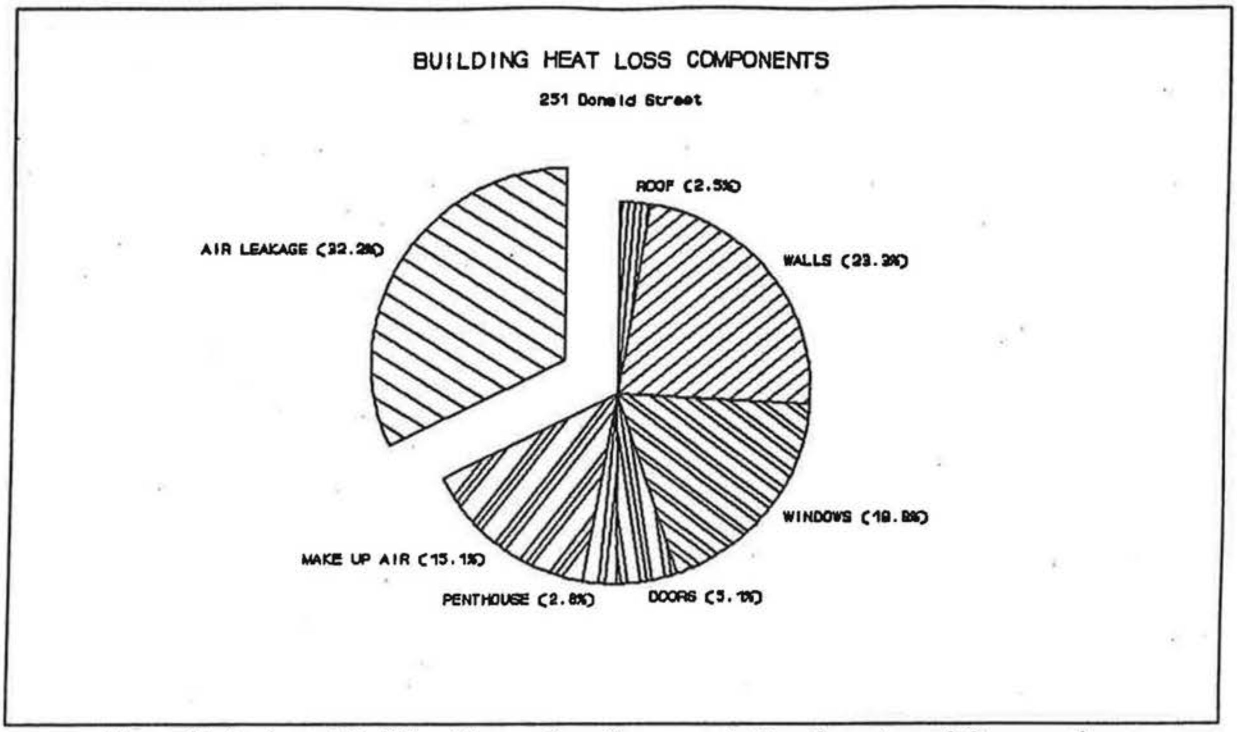


Figure 17: Estimated Building Energy Loss Components Based on Annual Consumption.

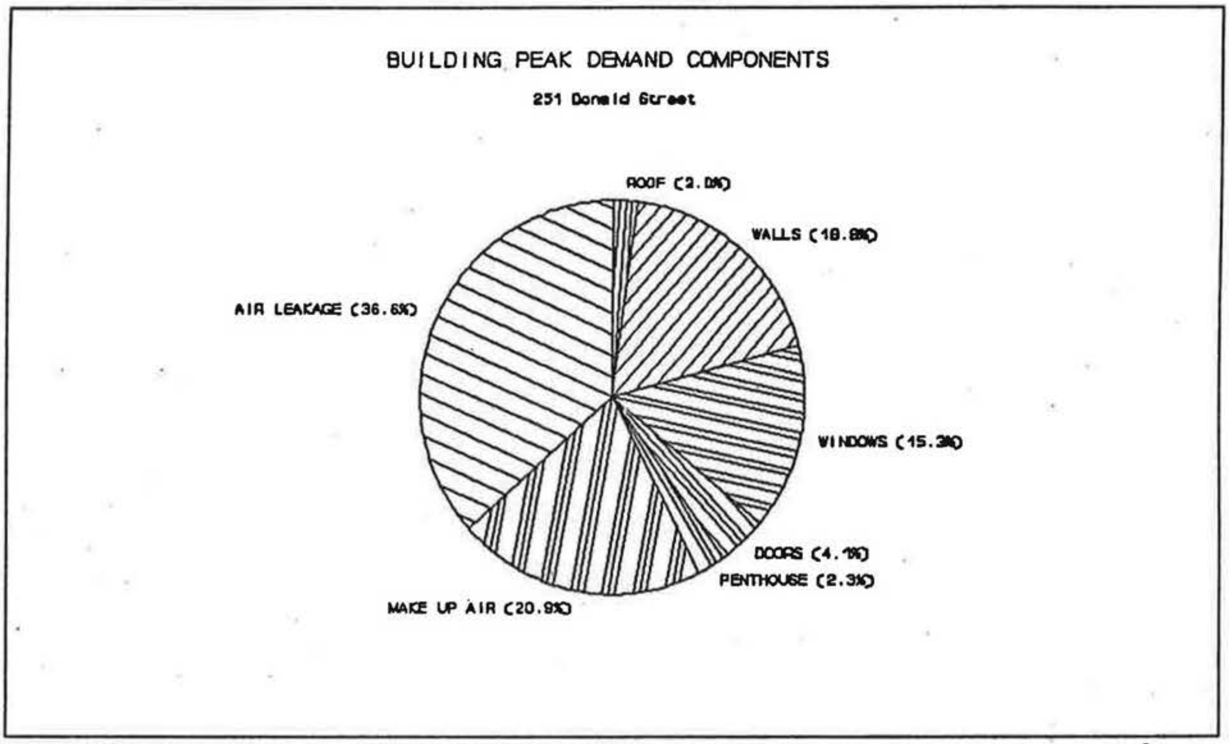


Figure 18: Estimated Building Peak Power Demand Components for Donald Street Building (at -20 °C and 8.89 m/s).

As shown in Figure 15, the monthly base power demand varies from 234 kW to 287.1 kW. The monthly heating demand varies from 0 to 612.9 kW depending on degree days. The total monthly power demand varies from 234 kW to 900 kW. In 1989, the total power demand charges were $23,075 - approximately 16.5% of the total bill.

As shown in Figure 16, space heating represents the largest component at 1,330 MWh, which is 51.5% of the total energy consumption. Lighting takes 18.5%, suite appliances 13.7%, elevator transportation almost 10.5%, and hot water 3.1% of the total. Laundry, suite fans, car block heaters, and air conditioners together consume 2.7%.

Figure 17 shows the calculated space heating energy and power requirements. As shown, the air leakage component takes 32% of the space heating energy. The heat losses through air leakage, walls and windows account for almost 75% of the building's total energy consumption.

Figure 18 shows the components of peak heating demand simulated for this building assuming an outdoor temperature of -20 C and a wind velocity of 32 kmph. The "uncontrolled" air leakage represents almost 37% of peak demand needs. Air-sealing could substantially reduce the peak heating requirements, as will be seen.

The infra-red thermography (IR) of this building showed the weakness typical of this type of building, including thermal bridging at the floor edges and into the balcony "fins", and air leakage at windows and in upper junctions [Scanada 1990].

3.1.2 Bridleview Condominium Building

The Bridleview York Condominium (YCC 449) is a 10 storey apartment building with 95 suites. This is a freehold condominium apartment building which is managed and maintained by Gelco Management Services Limited. Its 95 suites are all occupied. There are two buildings in the front and one building in the back which shields this building. The building is comprised of single self-contained (bachelor), one bedroom and two bedroom apartments. There is a lobby, games room and gathering hall on the first floor. These facilities are normally open between 08:00 and 22:00 hours. Photographs are included at the end of this chapter.

The construction is concrete flat plate, with no insulation at the floor perimeter. The walls are insulated with 35 mm polystyrene rigid insulation. This building has a length of 58.7 m, width of 17.7 m and height of 29.4 m. The total heated floor area is 9,825 m^2 and the volume is 25,455 m^3. There are two elevator shafts and two stairwells are located at the end of the building, and one garbage chute in the centre.

Each suite is provided with the electric baseboard heaters for space heating purposes. The total installed capacity of the electric baseboard heating system is 920 kW. In this building, natural gas is utilized for hot water and for heating the building make-up air. The make-up air heating capacity is approximately 270 kW. The energy audit calculations do not include the component of natural gas fuel consumption.

Energy Audit

The total electric energy bill for the year 1989-90 was $92,546 - $ 9.42/m^2 or 170 kWh/m^2 of floor area. Analysis of energy use was performed by examining the monthly electricity bills for a period of 24 months. A load and energy usage pattern was developed on the basis of various equipment sizes and rating information obtained through physical examination and the manufacturer's information. Almost 96% of the annual energy consumption was accounted for in this analysis. Figure 19 shows the profile of base and space heating energy (supplied by electric only) consumption. The estimates of base electric consumption include the following: lighting needs for suites, corridors, stairwells, exit signs, penthouse and outdoors; and energy requirements for suite appliances, suite fans, laundry, elevators and air-conditioners. The total consumption profile includes the base and space heating requirements. As shown in Figure 20, the monthly base power demand varies from 120 to 160 kW. The monthly heating demand (electric only) varies from 0 to 377 kW depending on weather conditions. As shown in Figure 21, the space heating represents the largest component at 970 MWh, which is 58% of the total energy consumption. Figure 22 shows the components of peak heating demand simulated for this building assuming an outdoor temperature of -15 C and a wind velocity of 6.67 m/s. As shown, the air leakage component takes 32% of space heating needs. Air-sealing could substantially reduce the peak heating requirements, as will be seen.

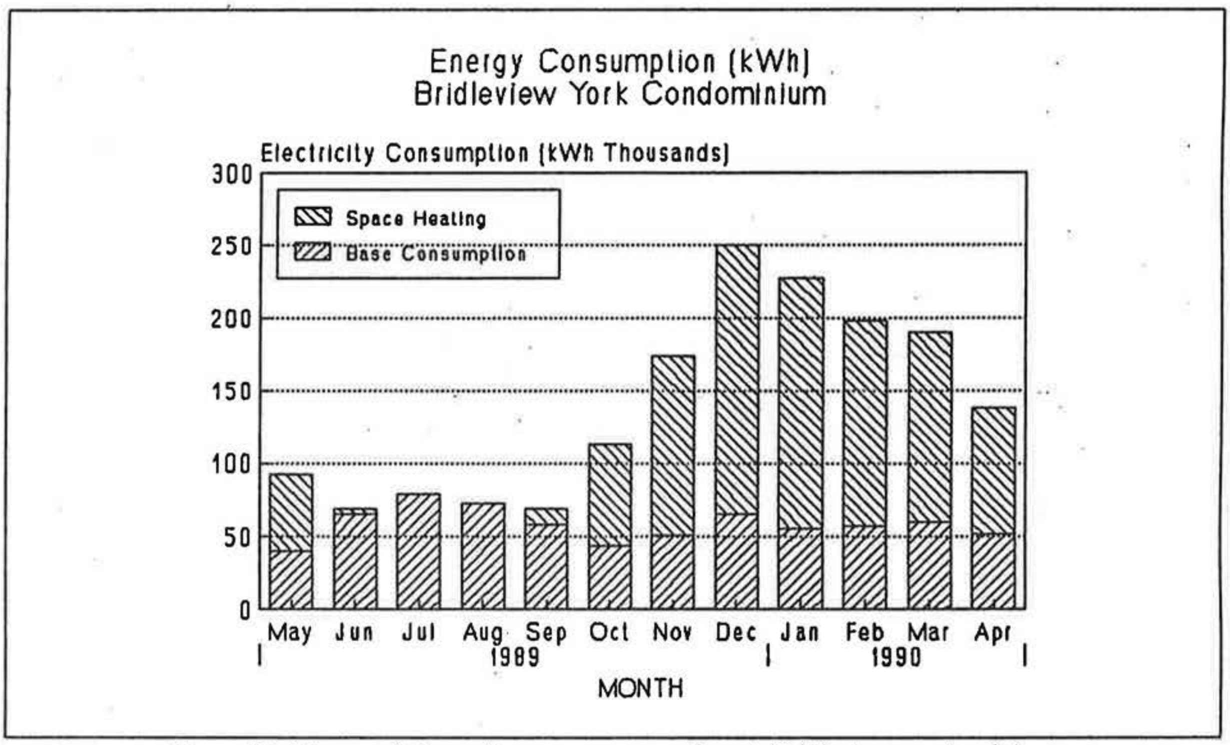


Figure 19: Measured Annual energy consumption at Bridleview condominium.

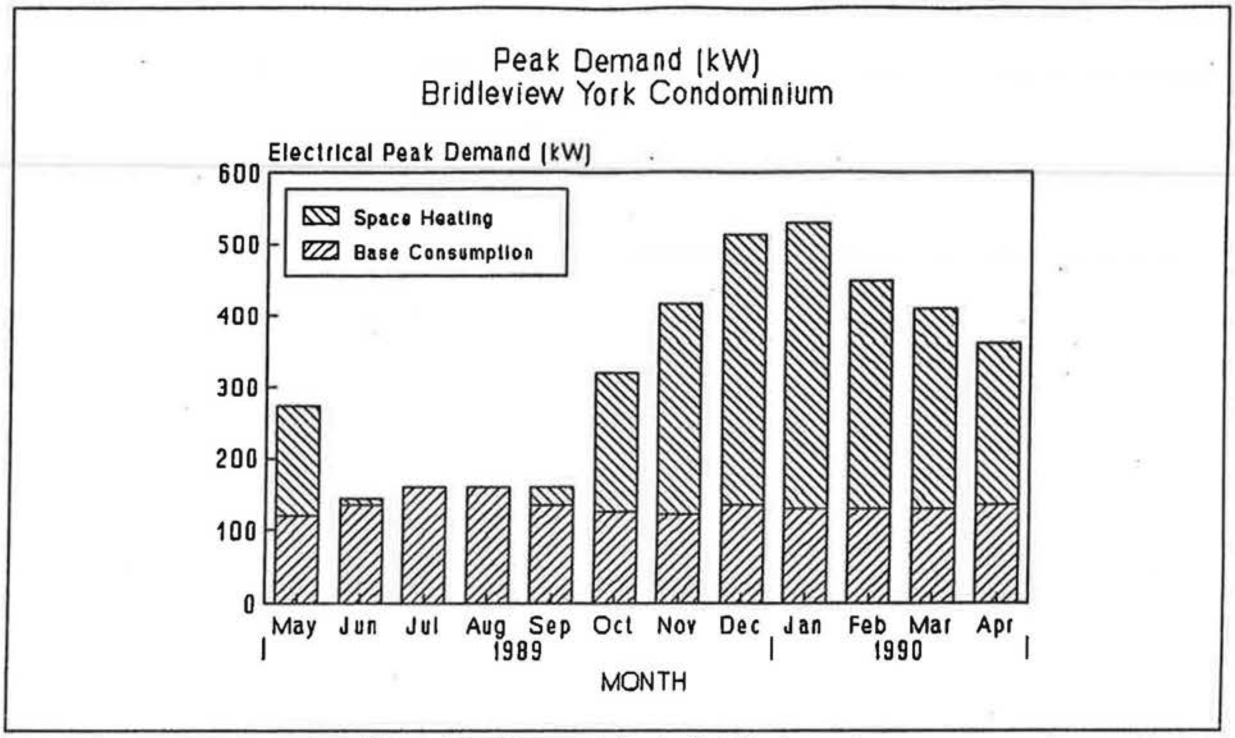


Figure 20: Measured Peak electric demand.

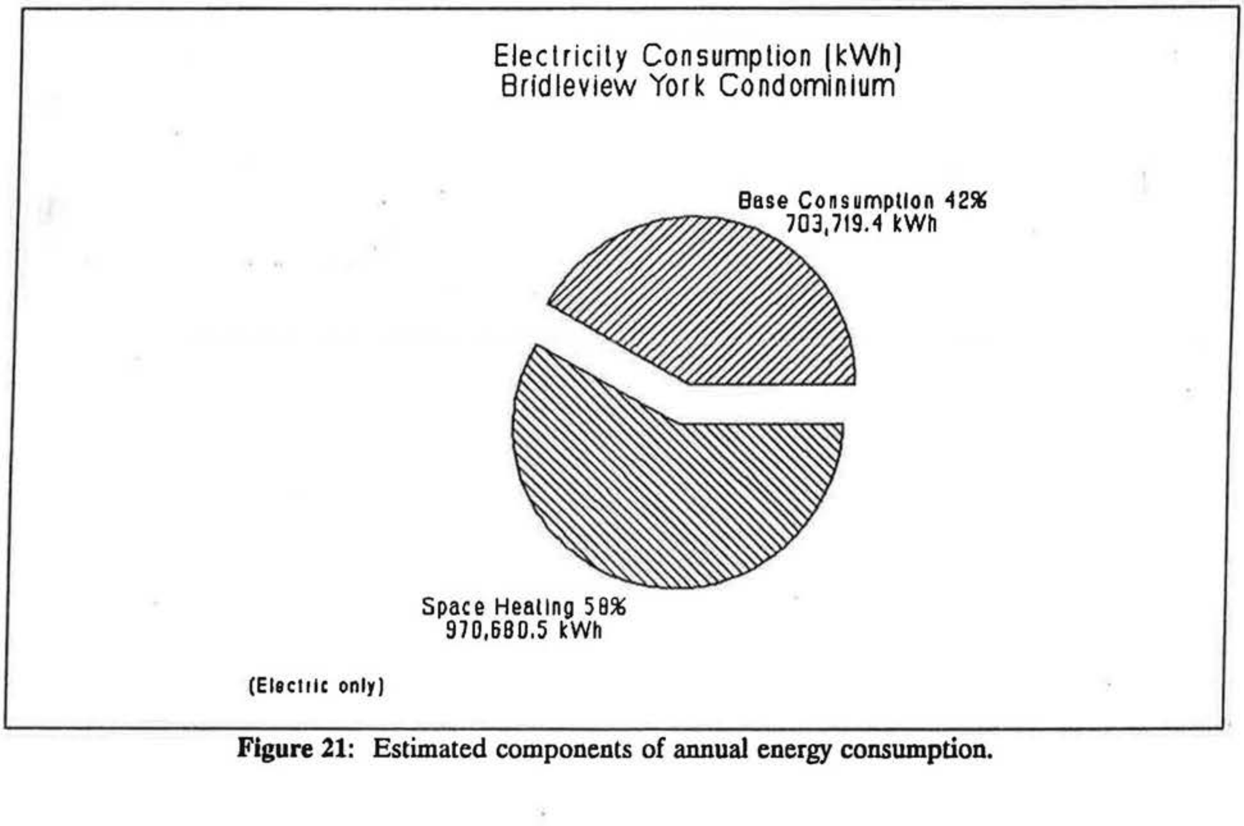


Figure 21: Estimated components of annual energy consumption.

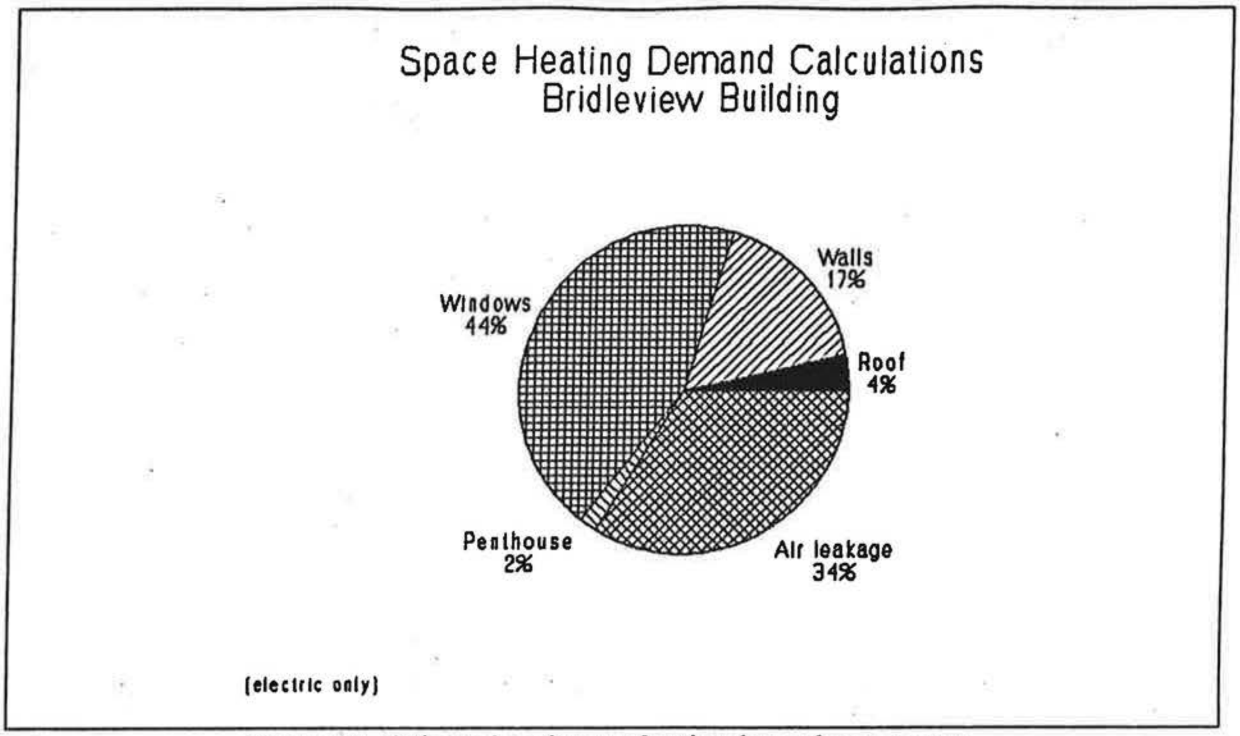


Figure 22: Estimated peak space heating demand components.

3.2 Work Plan and Field Implementation

The project team planned the air sealing work in three steps to assist and verify the "before" and "after" characteristics of the two test buildings. The steps were: before sealing, sealing, and after sealing.

Before Sealing:

1. Energy audit and predictive diagnosis of the potential for air leakage control

   The project team performed the detailed energy audit of two test buildings and established the peak power and energy consumption due to air infiltration as shown in the following sections.

2. Air leakage detection: visual and smoke pencil observations, simple and inexpensive airtightness tests

   The test buildings were visually inspected for air leakages and all imperfections were noted. Infra-red thermography was conducted to locate the air leakage paths. In-situ airtightness tests were conducted on individual suites in both these buildings to establish the path of air infiltration more accurately. Window air leakage tests were conducted, in place, to measure the difference between existing weatherstripping and new weatherstripping for air leakage control.

The air sealing estimation procedure, as described in the preceding section, was applied to predict the potential reductions in peak power and energy consumption. Based on these calculations, a detailed plan for the air sealing work was prepared.

3. Airtightness tests

The whole building airtightness test of the Donald Street building was conducted using the National Research Council of Canada's 24 m^3/s axial-vane fan. The method was based on CMHC protocol for the high-rise airtightness tests [CMHC 1990]. During the test, smoke pencils and draft sensors were used to determine and verify various leakage paths. A detailed log of the conditions was kept. The results were analyzed and compared with the air-sealing estimation procedure.

In the Bridleview building, the project team performed the airtightness tests of four individual storeys (floors) using the CMHC's test protocol for high-rise buildings. The results are presented in the following sections.

4. Energy and power monitoring

Continuous power monitoring was accomplished by installing data loggers. Ontario Hydro assisted in the installation of monitoring equipment and data collection. Monitoring in both buildings began in the fourth week of November 1990. The data was supplied to the project team on a bi-weekly basis.

5. Indoor air quality tests

The project team conducted several indoor air quality tests at the building. Relative humidity, carbon dioxide, and indoor and outdoor temperatures were recorded for a period of five days with continuous monitoring equipment. Formaldehyde and radon samples were taken at different locations.

<u>Air Sealing:</u>

Sealing work at the Bridleview building commenced in the second week of December 1990 and was completed on December 21, 1990. It was performed in the following steps:

1. sealing of all shaft leaks
2. sealing of all windows and doors
3. sealing of all building envelope leaks
4. sealing of miscellaneous leaks

First, all shaft leaks were sealed. The indoor envelope leaks were sealed in the following order: the bottom four storeys, top three storeys and the remaining middle storeys.

Air sealing work in the 251 Donald Street building began in the second week of January 1991 and was completed on January 25, 1991. The work was performed in the following steps:

1. sealing of all shaft leaks: penthouse, mechanical rooms, garbage chute, stairwells...
2. sealing of all windows, doors and envelope leaks on 1st to 7th floor
3. sealing of all windows, doors and envelope leaks on 16th to 22nd floor
4. sealing of all windows, doors and envelope leaks on 8th to 15th floor
5. sealing of all miscellaneous leaks

During this time, the energy and power consumption was continuously monitored.

After Sealing:

1. Airtightness tests

   The whole building airtightness test of the Donald Street building was conducted using the NRC's axial-vane fan to measure the improvements in airtightness. The "before-sealing" test conditions were repeated (as far as possible) to conduct the airtightness test. The test method was based on the CMHC protocol for the high-rise airtightness tests [CMHC 1990]. During the test, smoke pencils and draft sensors were used to determine and verify various leakage paths. The results were analyzed and compared with the air-sealing estimation procedure.

   In the Bridleview building, the project team performed airtightness tests of four individual storeys (floors), similar to the "before air sealing" tests, using the CMHC's test protocol. The results are presented in the following section.

2. Data analysis of energy consumption

   The monitored energy consumption data was compared to determine the impact of air-sealing on peak power demand.

3. Indoor air quality tests

   The project team conducted similar indoor air quality tests at the building.

3.3 Estimation of Air-Sealing Potential

3.3.1 Donald Street Building

A detailed inspection of the 251 Donald Street building was performed in the month of June 1990 to assess the air leakage and evaluate the control strategies. Appendix A contains the detailed field inspection data for this building and calculations of potential energy savings. Tables 8 and 9 present the summary of these calculations with the modified air sealing assessment procedure.

The field inspection showed that the total leakage area in the building, before air sealing, was 2.72 m^2. The air leakage rate at the peak winter conditions was 5,993 L/s, resulting in a heating demand of 265 kW - approximately 42% of peak heating load. By assuming that the air sealing can reduce the uncontrolled air leakage by 32%, the resulting reduction in peak heating demand would be approximately 85 kW.

In this building the windows and doors represent 68% of the total air leakage in the building. The shafts constitute about 14% of leakages. Remaining leaks are from the building envelope and miscellaneous components. Figure 23 shows the profile of air infiltration and exfiltration through the building during peak winter design conditions. As shown in this figure, the majority of air-leaks (more than 80% of the total) occur in the top one-third height and bottom one-third height. The air-sealing strategy should consider the option of selective sealing of top and bottom storeys.

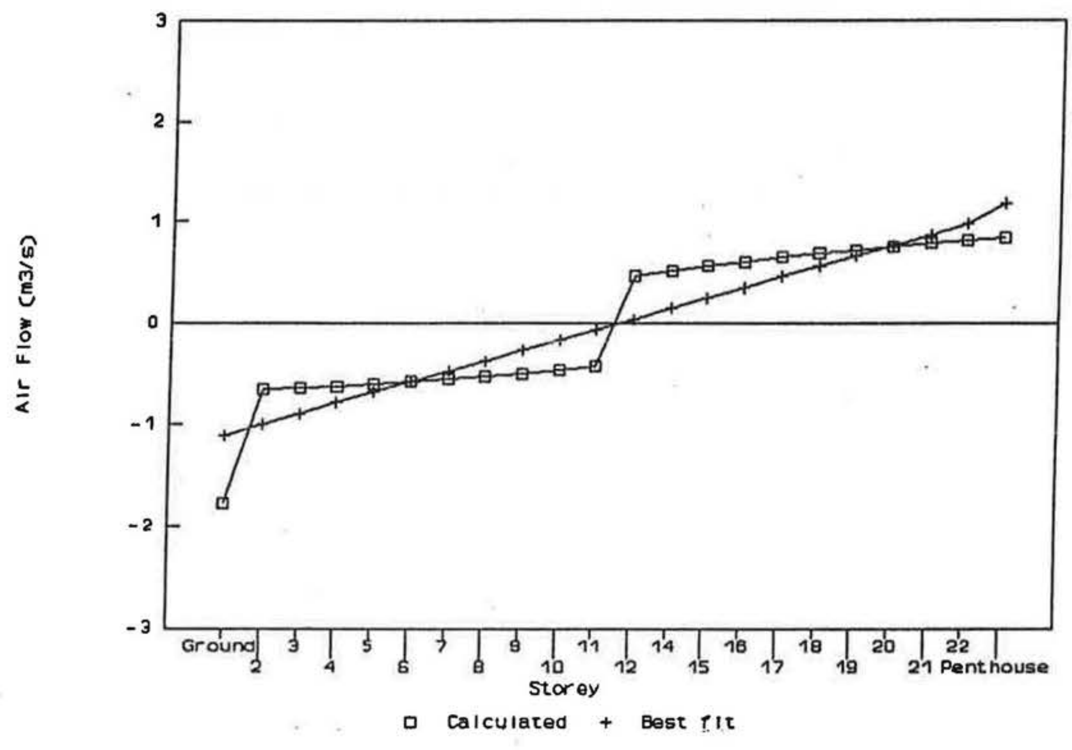


Figure 23: Estimated profile of air infiltration and exfiltration at peak winter design conditions for the 251 Donald Street building.

Table 8: Summary of assessment of air leakage and potential control at 251 Donald Street building.

	Windows	Doors	Envelope	Shafts	Misc.	Total
Effective air leakage (L/s)	2517	1558	360	839	719	5933
Peak Infiltration Load (kW)	112.7	69.7	16.1	34.6	32.2	265.6
Reductions at 32% sealing (kW)	36	22	5.2	11.5	10.3	85
Percentage of total reductions	**42**	**26**	**6**	**14**	**12**	**100**

Table 9: Assessment of air leakage and potential control at 251 Donald Street building in Ottawa.

Storey	Height (m)	Stack Pressure Ps (Pa)	Wind Speed (m/s)	Wind Pressure Pw (Pw)	Leakage Area						Q- Flow					
					Windows (m2)	Doors (m2)	Envelope (m2)	Shafts (m2)	Misc. (m2)	Total (m2)	Windows (m3/s)	Doors (m3/s)	Envelope (m3/s)	Shafts (m3/s)	Misc. (m3/s)	Total (m3/s)
Ground	0.100	-32.425	2.066	0.550	0.061	0.064	0.034	0.126	0.022	0.308	0.363	0.378	0.201	0.744	0.131	-1.816
2	3.035	-29.141	5.371	3.722	0.080	0.033	0.000	0.000	0.002	0.115	0.474	0.195	0.000	0.000	0.009	-0.678
3	5.690	-26.171	6.404	5.291	0.080	0.033	0.000	0.000	0.002	0.115	0.464	0.190	0.000	0.000	0.009	-0.663
4	8.344	-23.201	7.129	6.557	0.080	0.033	0.000	0.000	0.002	0.115	0.451	0.185	0.000	0.000	0.009	-0.645
5	10.998	-20.231	7.702	7.653	0.080	0.033	0.000	0.000	0.002	0.115	0.437	0.179	0.000	0.000	0.009	-0.625
6	13.653	-17.261	8.183	8.638	0.080	0.033	0.000	0.000	0.002	0.115	0.421	0.173	0.000	0.000	0.008	-0.602
7	16.307	-14.291	8.601	9.542	0.080	0.033	0.000	0.000	0.002	0.115	0.404	0.166	0.000	0.000	0.008	-0.577
8	18.961	-11.321	8.971	10.383	0.080	0.033	0.000	0.000	0.002	0.115	0.385	0.158	0.000	0.000	0.008	-0.551
9	21.615	-8.351	9.307	11.173	0.080	0.033	0.000	0.000	0.002	0.115	0.365	0.150	0.000	0.000	0.007	-0.523
10	24.270	-5.381	9.613	11.922	0.080	0.033	0.000	0.000	0.002	0.115	0.344	0.141	0.000	0.000	0.007	-0.492
11	26.924	-2.411	9.897	12.635	0.080	0.033	0.000	0.000	0.002	0.115	0.321	0.132	0.000	0.000	0.006	-0.459
12	29.578	0.559	10.16	13.319	0.080	0.033	0.000	0.000	0.002	0.115	0.308	0.126	0.000	0.000	0.006	0.441
14	32.233	3.529	10.408	13.975	0.080	0.033	0.000	0.000	0.002	0.115	0.346	0.142	0.000	0.000	0.007	0.495
15	34.887	6.500	10.642	14.608	0.080	0.033	0.000	0.000	0.002	0.115	0.380	0.156	0.000	0.000	0.008	0.543
16	37.541	9.470	10.86	15.221	0.080	0.033	0.000	0.000	0.002	0.115	0.411	0.169	0.000	0.000	0.008	0.588
17	40.196	12.440	11.07	15.814	0.080	0.033	0.000	0.000	0.002	0.115	0.440	0.180	0.000	0.000	0.009	0.629
18	42.850	15.410	11.27	16.391	0.080	0.033	0.000	0.000	0.002	0.115	0.466	0.191	0.000	0.000	0.009	0.667
19	45.504	18.380	11.46	16.952	0.080	0.033	0.000	0.000	0.002	0.115	0.492	0.202	0.000	0.000	0.010	0.703
20	48.158	21.350	11.64	17.499	0.080	0.033	0.000	0.000	0.002	0.115	0.515	0.212	0.000	0.000	0.010	0.737
21	50.813	24.320	11.82	18.033	0.080	0.033	0.000	0.000	0.002	0.115	0.538	0.221	0.000	0.000	0.011	0.770
22	53.467	27.290	11.99	18.554	0.080	0.033	0.000	0.000	0.002	0.115	0.560	0.230	0.000	0.000	0.011	0.801
Penthouse	58.750	33.201	12.31	19.559	0.000	0.000	0.060	0.051	0.000	0.111	0.000	0.000	0.446	0.381	0.000	0.827
				Total	1.669	0.724	0.094	0.177	0.054	2.718						

3.3.2 Bridleview Building

A detailed air-sealing assessment and energy audit of this building was performed in the month of November 1990. Air leakage was one of the major heat loss components for this 10 storey apartment building. It accounted for more than 19% of the total annual space heating energy and almost 32% of the peak power demand due to space heating. The assessment of air-leakage and its potential control in this building is summarized as follows:

The estimated air infiltration rate for this building at the winter design conditions (an outdoor temperature of -18 °C and 6.67 m/s wind) was 1,880 L/s (0.19 L/s.m² of floor space) before air sealing. The peak heating demand due to this peak air-leakage rate is 86 kW. The energy analysis showed that the make-up air heating constitutes approximately 18% of the total space heating load during the winter design conditions. As the make-up air is heated with natural gas and the suite space heating is provided by electric baseboards, the peak electric demand due to air-leakage in the building is approximately 71 kW.

It was assumed that the air sealing would reduce the peak electric demand due to air leakage by 40%, resulting in peak electric demand shaving by approximately 28 kW. [Due to space considerations, relevant tables, graphs and calculations are not included in this report; these were submitted with the Progress Reports.]

3.4 Airtightness Tests

3.4.1 Donald Street Building

The general procedure for conducting whole-building leakage tests has been described in the Institute for Research in Construction report to Canada Mortgage and Housing Corporation entitled "Establishing the Protocols for Measuring Air Leakage and Air Flow Patterns in High-Rise Apartment Buildings" [CMHC 1990]. Specific details of the test conducted at 251 Donald Street are reported in Appendix C.

A large vane-axial fan with maximum capacity of 23,600 L/s was used to depressurize the building. The fan inlet was connected by 12 m of 0.9 m - diameter ducting to a plywood panel temporarily installed in the double doors adjacent to the garbage room on the west side of the building. The door panel and all joints in the duct/fan assembly were sealed with tape prior to testing. Airflow rates were measured upstream of the fan intake using a pair of total pressure averaging tubes. Flow rates are accurate to within 5% of the measured values. Photographs are attached at the end of this chapter.

Two tests were conducted. Test 1 was conducted on October 23, 1990 prior to air-sealing, and Test 2 on March 25, 1991 after the air-sealing work was completed. Weather conditions during these tests were as shown in Table 10.

Table 10: Weather conditions during airtightness tests

Weather Parameters	Test No. 1 October 23, 1990	Test No. 2 March 25, 1991
Outdoor temperature, °C	8.0	4.0
Indoor temperature, °C	22.0	23.0
Wind speed, m/s	5.13	2.23
Wind direction	NE	NE

Airtightness Test Results

The airtightness results are shown in Figures 24, 25 and 26.

Before Air Sealing

The airtightness results showed that this building had a net uncontrolled air leakage rate (infiltration or exfiltration) of more than 4,740 L/s at 10 Pa pressure difference. This infiltration component accounted for approximately 216 kW of the peak heating demand (assuming an outdoor temperature of -18 deg C; $Q\rho\Delta T$ (W) = 4,740 L/s * 1.2 kg/m^3 * 38 K).

After Air Sealing

The airtightness results after air-sealing showed that this building has a net uncontrolled air leakage (infiltration or exfiltration) rate of 3,225 L/s at 10 Pa pressure difference. This infiltration component accounts for approximately 147 kW of the peak space heating demand. The reduction in electric load due to air leakage is approximately 69 kW.

The reduction in space heating load at peak weather conditions would be approximately 69 kW based on the airtightness data. The airtightness measurements only account for the net reduction in air leakage through the building shell. The corridor supply air balancing, isolation of garbage rooms, sealing of stairway doors, pressurization of main hallways further reduces the driving potential for air leakage. This interior compartmentalization assists in proper air movement. The measured energy consumption data show greater reductions in electric demand at the peak weather conditions than is shown by airtightness data.

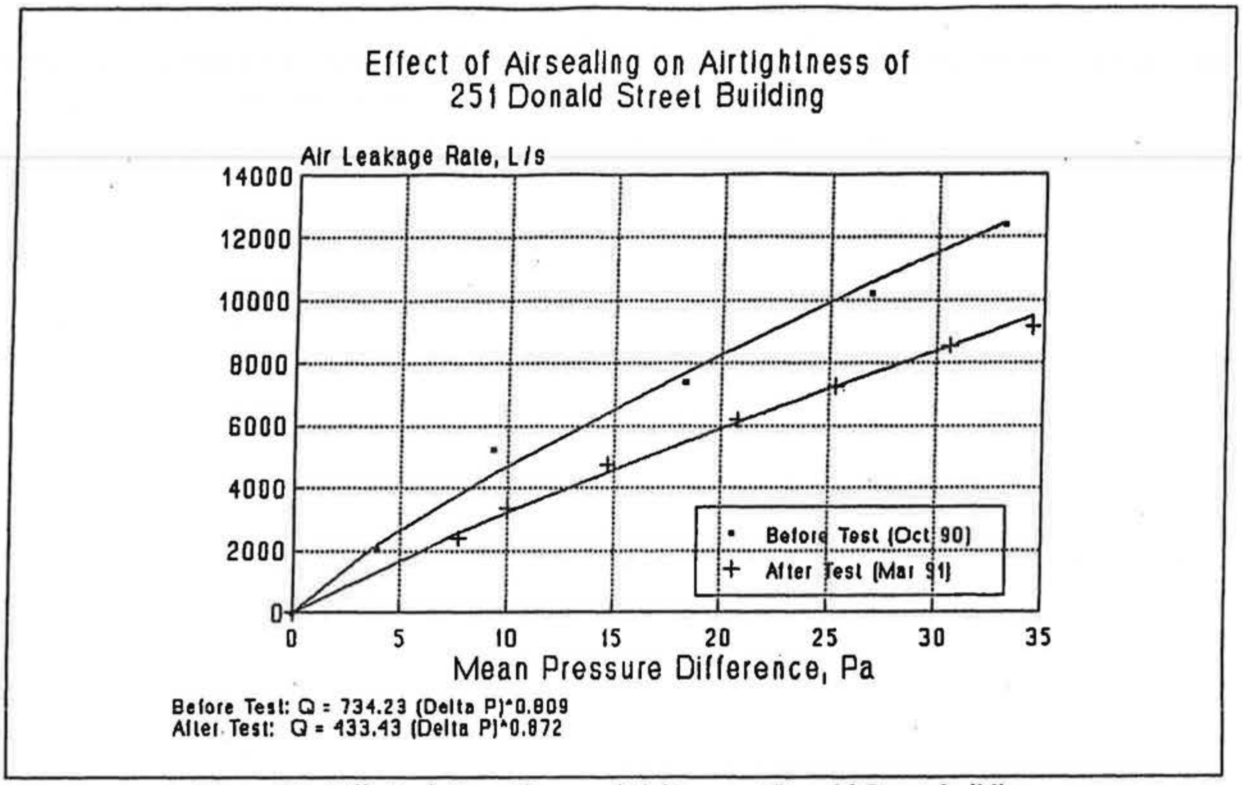


Figure 24: Effect of air sealing on airtightness at Donald Street building

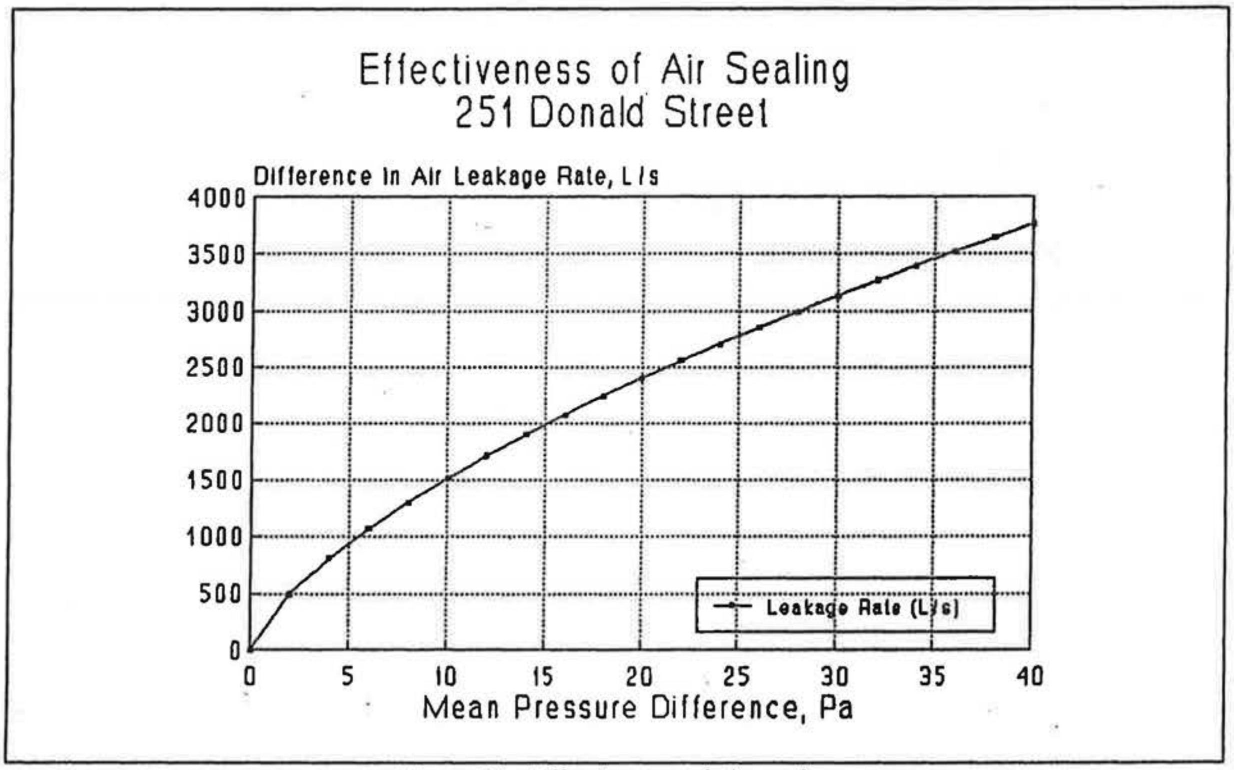


Figure 25: Effectiveness of air-sealing

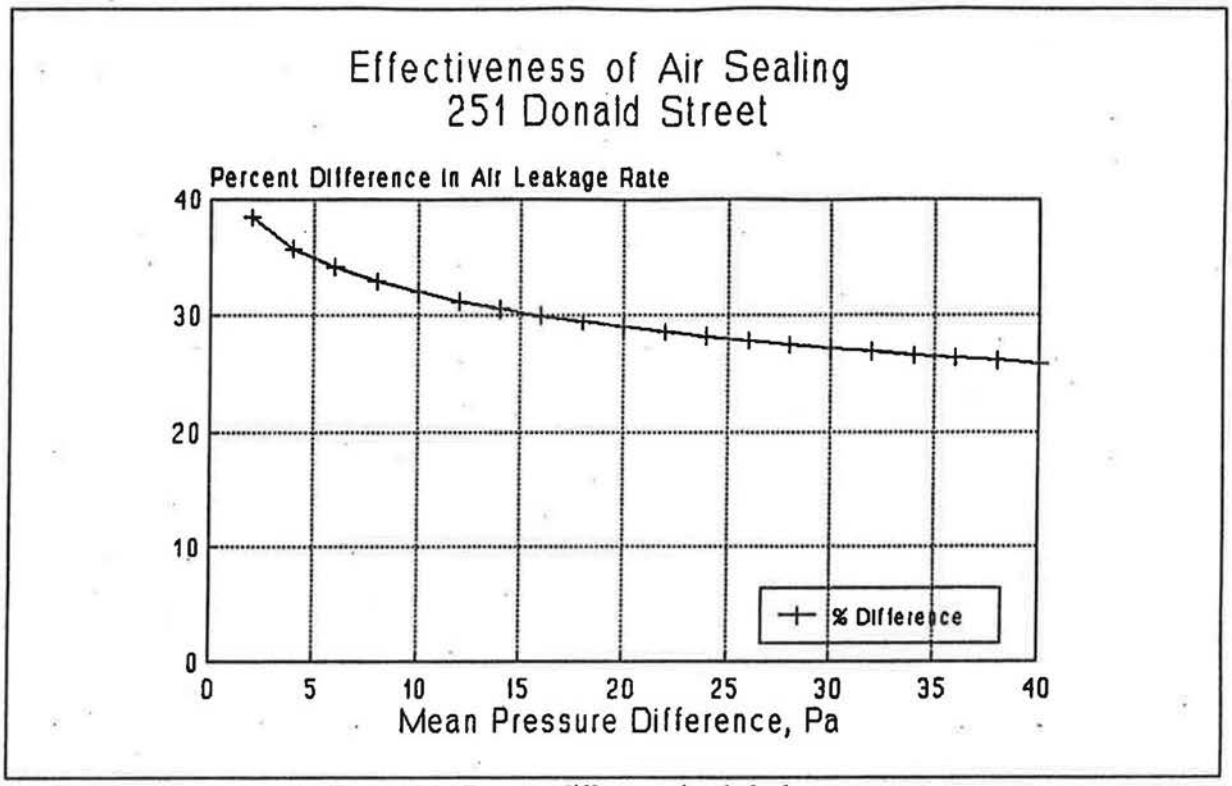


Figure 26: Percent difference in air leakage rate.

3.4.2 Bridleview Building

<u>Airtightness Test Results</u>

<u>Before Air Sealing</u>

The airtightness of four floors was performed as per the CMHC protocol for measuring air leakage and air flow patterns in high-rise apartment buildings [Magee and Shaw 1990]. Four floors were selected: ground floor, 5th floor, 9th floor and top floor. Air leakage characteristics of ground floor were measured using the two-fan method, in which the pressure difference between first floor and ground floor was kept at zero. For measuring airtightness of 5th floor, three fan method was used to isolate this floor. Air leakage through 4th and 6th floor was isolated by keeping the pressure difference between 4th and 5th, and 5th and 6th at zero. Similarly 9th and top floor airtightness was measured. These airtightness results were extrapolated to obtained the overall airtightness of the building.

The airtightness results showed that this building had a net uncontrolled air leakage rate (infiltration or exfiltration) of more than 1,885 L/s at 7 Pa pressure difference. This infiltration component accounted for approximately 86 kW of the peak heating demand (assuming an outdoor temperature of -18 deg C; $Q\rho\Delta T$ (W) = 1,885 L/s * 1.2 kg/m^3 * 38 K). In the Bridleview building, natural gas is utilized for heating the building make-up air. Each suite and room is provided with electric baseboard heaters for the space heating purpose. Energy audit of this building showed that the make-up air was approximately 18% of the total space heating requirements. Therefore, the electric load due to air leakage is approximately 71 kW.

After Air Sealing

The preliminary analysis of airtightness results after air-sealing showed that this building has a net uncontrolled air leakage (infiltration or exfiltration) rate of 1,165 L/s at 7 Pa pressure difference. This infiltration component accounts for approximately 53 kW of the peak space heating demand (make-up air gas heating plus electric baseboards). The electric load due to air leakage is approximately 43 kW (53 - 0.18*53).

The reduction in space heating load at peak weather conditions would be approximately 28 kW based on airtightness data. The airtightness measurements only account for the net reduction in air leakage through the building shell. The corridor supply air balancing, isolation of garbage rooms, sealing of stairway doors, and pressurization of main hallways further reduces the driving potential for air leakage. This interior compartmentalization assists in proper air movement. The measured energy consumption data show greater reductions in electric demand at the peak weather conditions than can be obtained from airtightness data.

3.5 Comparison of Energy Consumption Before and After Air Sealing

In the development of the calculation procedure, the "first-cut" air leakage assessment procedure was modified using the field monitoring data to better assess the leakage paths and to predict reasonable air-sealing effectiveness (the preliminary method was presented in Progress Report #1). The main objective of the comparison is to obtain the net change in peak heating demand before and after air sealing. Depending on the selection of similar weather periods, the change in peak demand may or may not be the same which may occur on a winter design day leading to the utility peak. If the similar weather periods match with the winter design criteria for the building, then the change in peak demand due to air sealing should be considered as the "air sealing potential". The following sections presents the calculation procedure and estimation of air-leakage rates using the air leakage assessment method and the monitored data.

3.5.1 Calculation Procedure

The effect of air sealing on peak electric demand and energy consumption was determined using the measured data of electric energy consumption. The calculation procedure consists of two components: (i) comparison of energy consumption profile during the similar weather periods before and after air sealing, and (ii) computer simulation and verifications. This calculation method was developed based on ASHRAE recommended energy estimating methods [ASHRAE 1989]. Each of the above component is explained in the following steps:

Comparison of energy consumption profile during the similar weather periods:

- Selection of typical sets of similar weather periods before and after air sealing depends on several factors: (i) the 36 to 48 hours of similar weather period should be between working days of Monday to Friday, (ii) all building heating and ventilation equipment is available during the similar weather periods, and (iii) it is assumed that the occupants behaviour is comparable.

  The similar weather periods are selected by comparing the mean outdoor temperature, average wind speed, wind direction and sunshine hours. It may be difficult to match the profile of outdoor temperature or wind speed on an hour by hour basis. Therefore, a 3-hour average of outdoor temperature or wind speed can be utilized for selecting the "similar" weather periods. Record the range of temperature and wind speed variations on these days.

- Comparison of hourly energy profile for similar weather periods should also look in to the general pattern of demand during those days. If there is sudden change in the peak electric demand due to equipment or other behaviour, these profiles should not be used for comparison.

- If there is large variation in the number of sunshine hours or wind velocity apply proper correction factors to the monitored energy consumption data. The *correction factors* can be determined using the compute simulation techniques described in the next component.

- For similar weather periods before and after air sealing, the difference in peak demand can be considered as the "net" impact of air sealing. Depending on the selection of similar weather periods, the change in peak demand may or may not be the same which may occur on a winter design day leading to the utility peak. If the similar weather periods match with the winter design criteria for the building, then the change in peak demand due to air sealing should be considered as the "air sealing potential".

Computer simulation and verifications:

- Obtain the detail information about the building to perform hourly energy simulation using a commercially available energy simulation program such as BESA DESIGN or DOE 2.1D. The input data required to perform hourly analysis includes some of the following parameters: building dimensions and layout, thermal resistance of building envelope, heating and ventilation system, operational schedules, and weather data. Using these data determine the hourly profile of electrical load during the heating season. Compare the hourly energy profile with the measured data. The building description and operational schedules can be adjusted to match the measured mean energy consumption for a period of five to seven days. This procedure assists in establishing a "base case".

- The "base case" can be used to generate the *correction factor* for two "similar weather days". The *correction factor* accounts for difference in solar gains and minor differences in hourly weather parameters. This correction factor should be applied to generated the "real" profile of energy consumption pattern.

3.5.2 Donald Street Building

Energy consumption in the 251 Donald Street building in Ottawa was continuously monitored at 15 minute intervals. The total electrical supply to the building and the hot water load were monitored from November 22, 1990 to May 31, 1991. The monitored data was analyzed to determine the impact of air sealing on energy consumption.

The air sealing work in the Donald Street building was completed on January 23, 1991. The similar weather periods (ambient temperature and wind speed) between December 1 to January 13 (before air-sealing) and January 24 to March 31, 1991 (after air-sealing) are used to determine the effect of air-sealing on power consumption. Appropriate correction factors have been used to account for solar gains (for instance, a December day is shorter than a January or February day) and weather effects as explained in the previous section. Hot water system conservation measures (low-flow showerhead) were implemented during the month of January 1991. Therefore, the present analysis does not include the hot water electric loads.

Figures 27 to 37 show the profile of electric demand and energy consumption for the building (excluding electric consumption for the hot water). These figures show the daily minimum and maximum electric demands and energy consumption due to base (lighting, appliances, other use) and space heating needs.

For a comparison, the energy consumption before and after air-sealing was analyzed using the four sets of similar weather days. These sets were selected by observing the hourly weather data for Ottawa as supplied by Environment Canada. These sets are as follows:

Table 11: Data sets used for the comparison of electric load.

Set	Day	Ambient Temperature (C)			Wind Speed (km/h)	Heating Degree Days	Sunshine Hours
		Max	Min	Mean			
1	January 10	-8.8	-22.0	-15.4	16.7 W	33.4	7.9
	February 16	-8.4	-21.6	-14.8	17.3 W	32.5	7.8
2	January 11	-16.4	-22.0	-19.2	20.4 E	37.2	1.6
	January 25	-14.5	-26.9	-20.7	14.5 S	38.7	2.9
3	January 5	-3.2	-9.7	-6.5	9.5 S	24.5	0
	February 13	-4.9	-10.2	-7.6	9.3 E	25.6	1.5
4	December 20	-11.2	-18.2	-14.7	14.7 E	32.7	7.6
	February 11	-6.8	-17.8	-12.3	15.7 N	30.3	8.6

The hourly space heating loads were calculated using the building description, weather data and operation schedules for December 20, January 5, 10 and 11. The building description and operation schedules were adjusted to match the measured mean energy consumption for these days. This procedure enabled the establishment of a "base case" for the building description before the air-sealing.

The further energy analysis for January 25, February 11, 13 and 16 was performed using the hourly weather data for those days with the same building description file. The energy consumption for January 25, February 11, 13 and 16 (period after air-sealing) provided an approximate profile of electric loads on the building, assuming that the building was not air-sealed. The difference in the electric load, on two "similar" days, is generally due to solar gains and a difference in the weather profile. This difference in electric load is used in correcting the actual load measurements for the building.

The comparison of electric loads is shown in Figures 38 to 41 and in Table 12.

Table 12: Comparison of Peak Demand Before and After Air Sealing.

Data Set		Building Demand (kW)	Average Building Demand (kW)	Energy Consumption (kWh)
1	Jan 10 (Before)	747.9	546.7	13120
	Feb 16 (After)	664.9	516.8	12403
	Difference	83 (11.1%)	30 (5.5%)	717 (5.5%)
2	Jan 11 (Before)	772.2	617	14808
	Jan 25 (After)	688.3	569.2	13660
	Difference	84 (10.9%)	48 (7.8%)	1148 (7.8%)
3	Jan 5 (Before)	483.5	418.9	10037
	Feb 13 (After)	419.2	350.9	8422
	Difference	64 (13.2)	68 (16.2)	1615 (16.2%)

The average difference in electric load before and after air-sealing was between 64 and 84 kW for the above mentioned days after applying proper corrections for the weather data. The reduction in heating load is approximately 10 to 13% of the peak electric load without considering hot water loads. When total electric supplied to the building is considered, the net difference in peak electric load is 9 to 10.5%.

A further analysis using the building description, and an assumed weather profile for a peak day (ambient temperature varying from -18 C to -21 C, and average wind speed of 24 km/hour) was simulated to predict the potential reductions in heating load. The reduction in heating load due to air-sealing would vary from 80 to 85 kW (approximately 10.5%) for this building on peak winter design days (calculated design load for such days may increase to about 780 kW). The above comparison also shows two data sets which were similar to the peak design conditions.

Comparison of Air-Sealing Assessment and Monitored Data

Using the air-sealing assessment procedure, it was estimated that the peak heating electric load due to uncontrolled air leakage in the building was approximately 264 kW (approximately 40% of space heating load) for the Donald Street building.

It was assumed that the air sealing of gross accessible leaks in the building envelope could result in achieving a 32% sealing effect overall. On that basis, the air-sealing assessment procedure predicted reductions in peak electric heating demand of 84 kW. A comparison of predicted reductions in peak heating demand and the energy consumption measurements show comparable results. The predicted reductions in peak heating demand are less than 5% higher than the measured results.

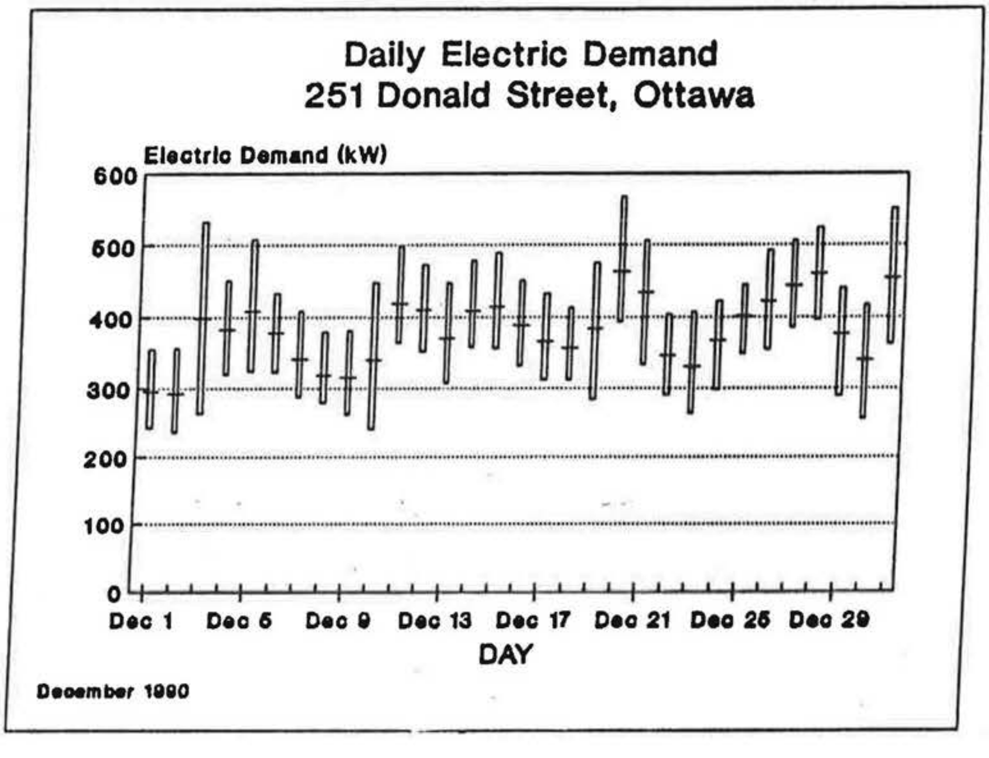


Figure 27: Daily electric demand - December 1990.

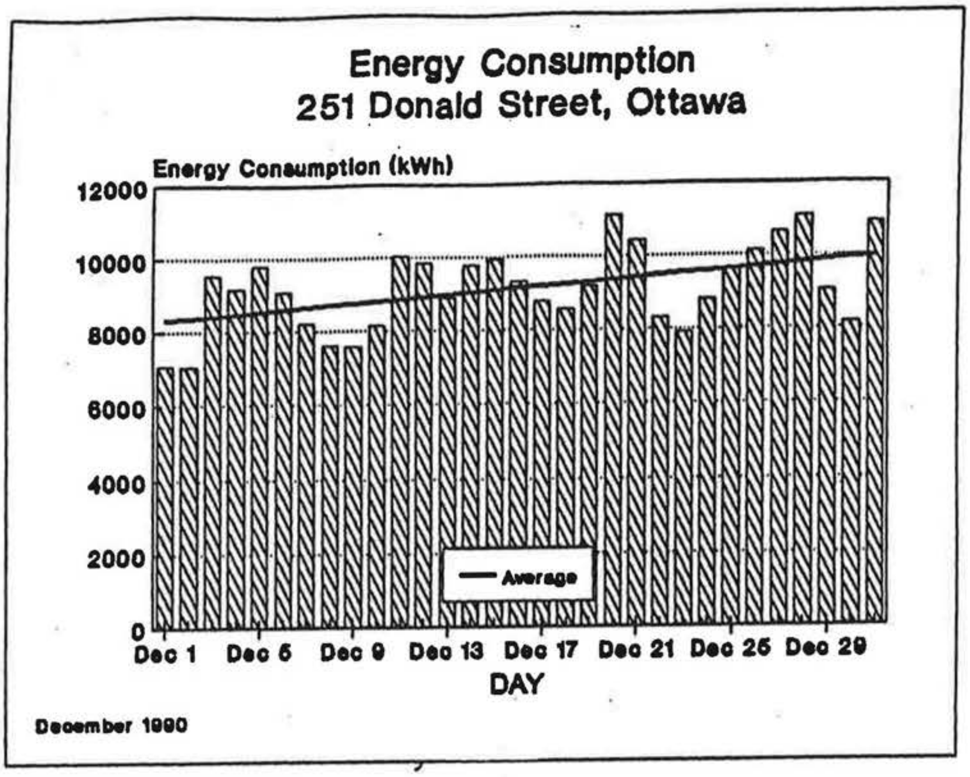


Figure 28: Energy Consumption - December 1990.

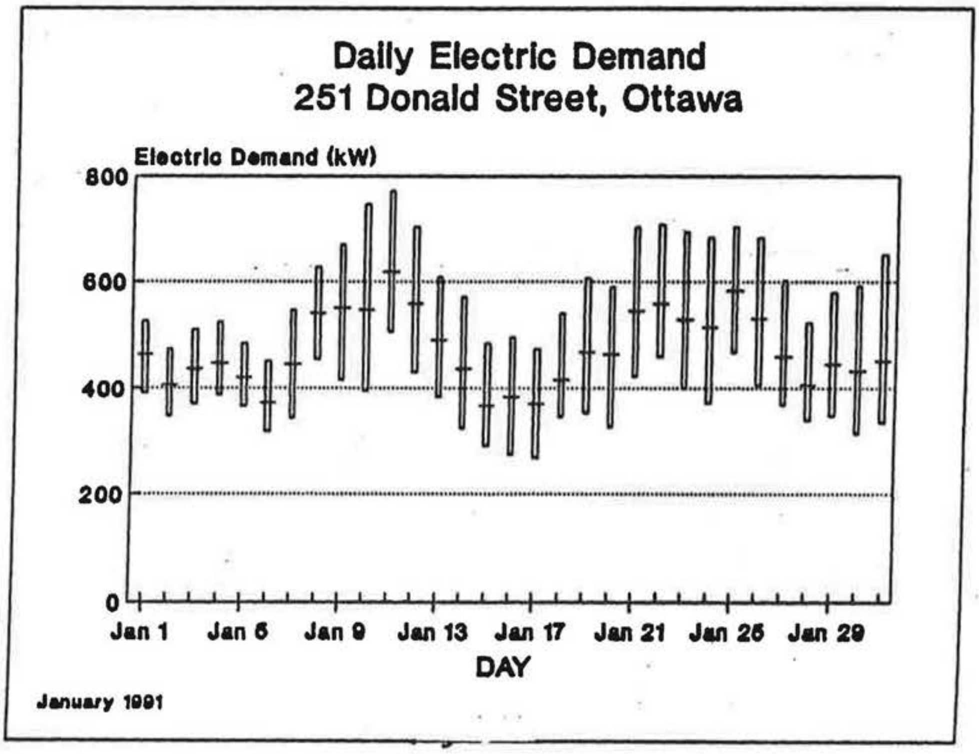


Figure 29: Daily electric demand - January 1991.

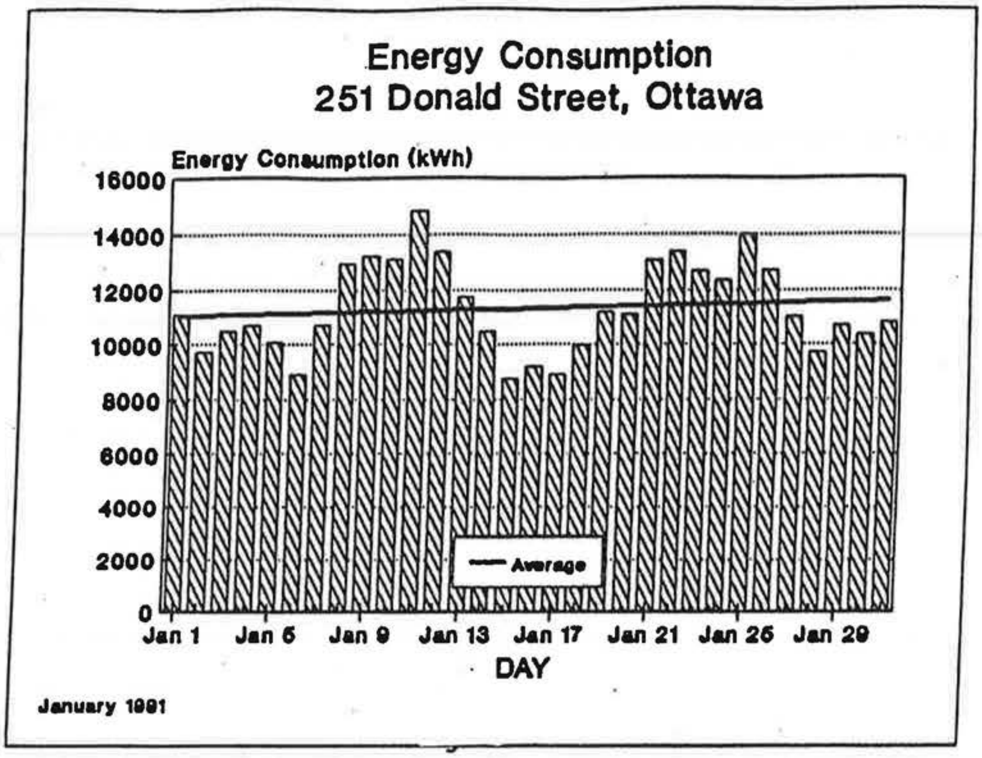


Figure 30: Energy Consumption - January 1991.

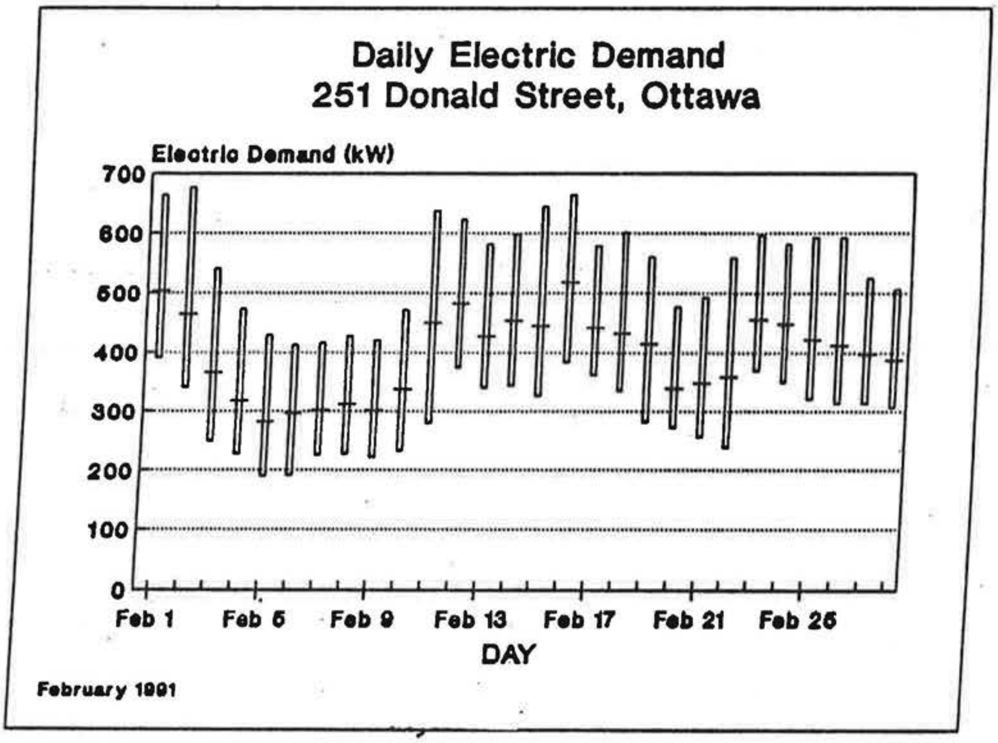


Figure 31: Daily electric demand - February 1991.

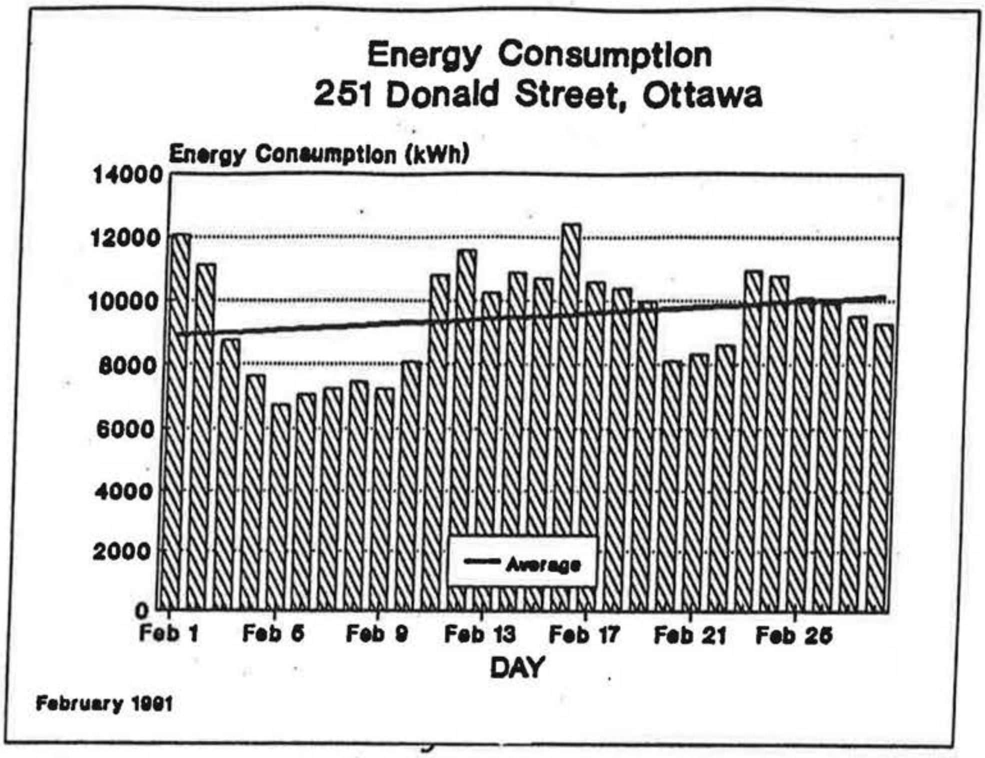


Figure 32: Energy Consumption - February 1991.

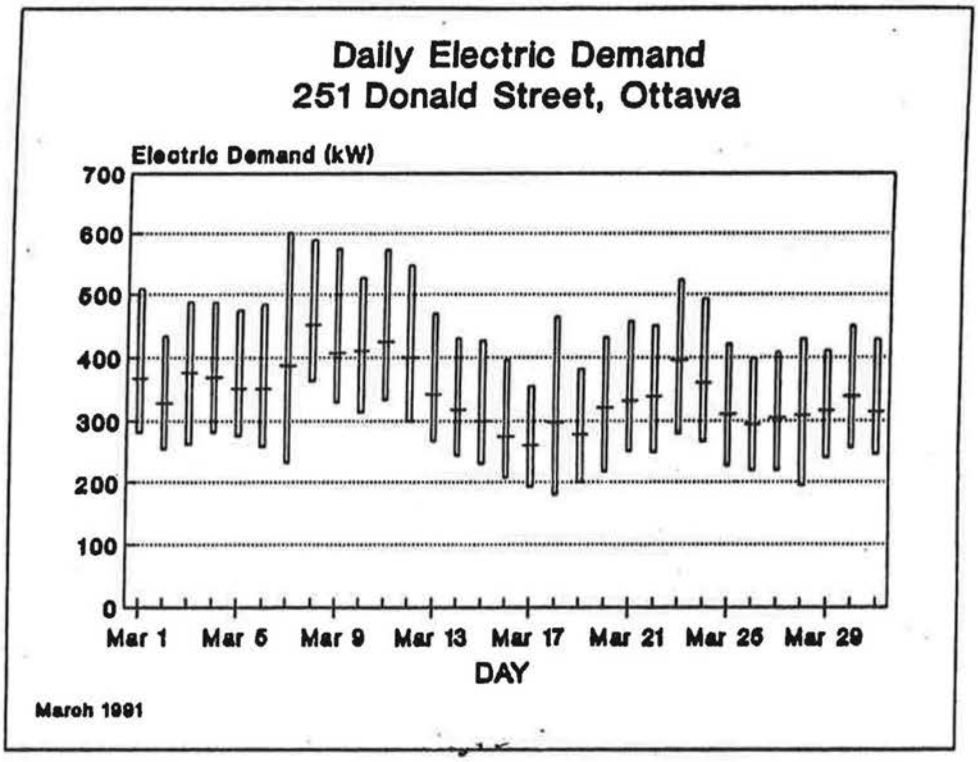


Figure 33: Daily electric demand - March 1991.

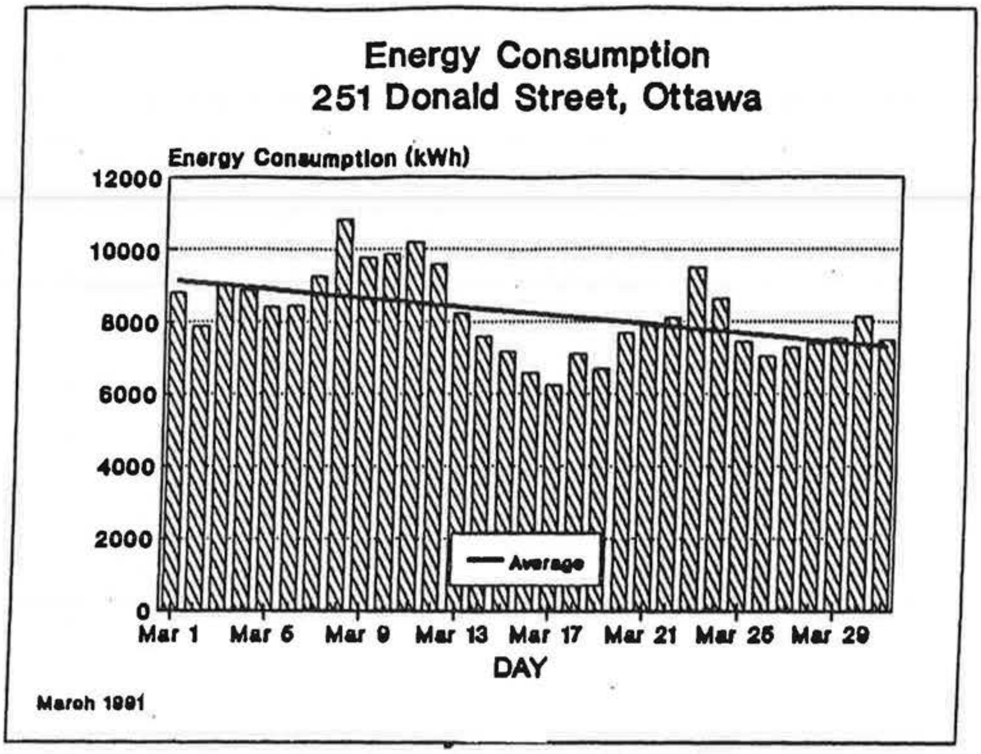


Figure 34: Energy Consumption - March 1991.

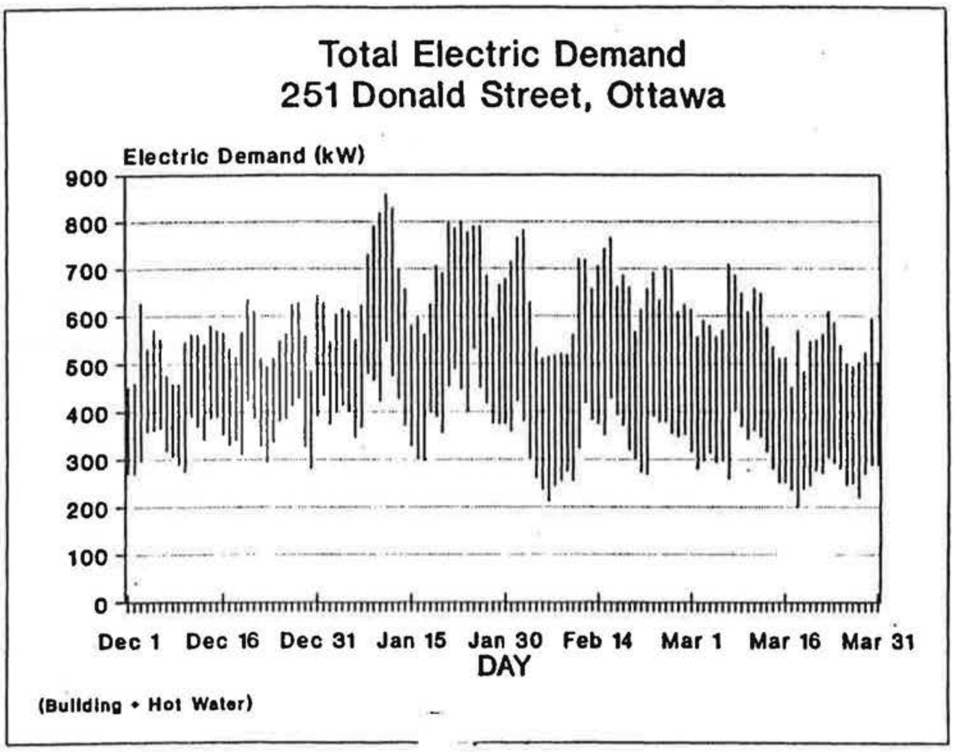


Figure 35: Total Daily electric demand - December to March.

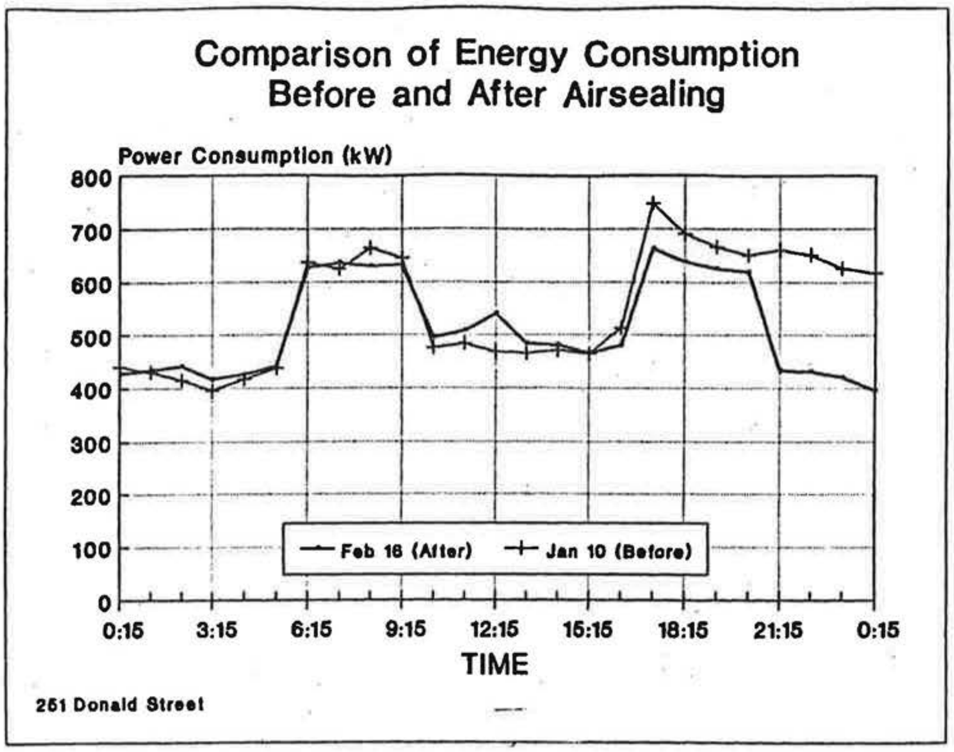


Figure 38: Comparison of peak demand.

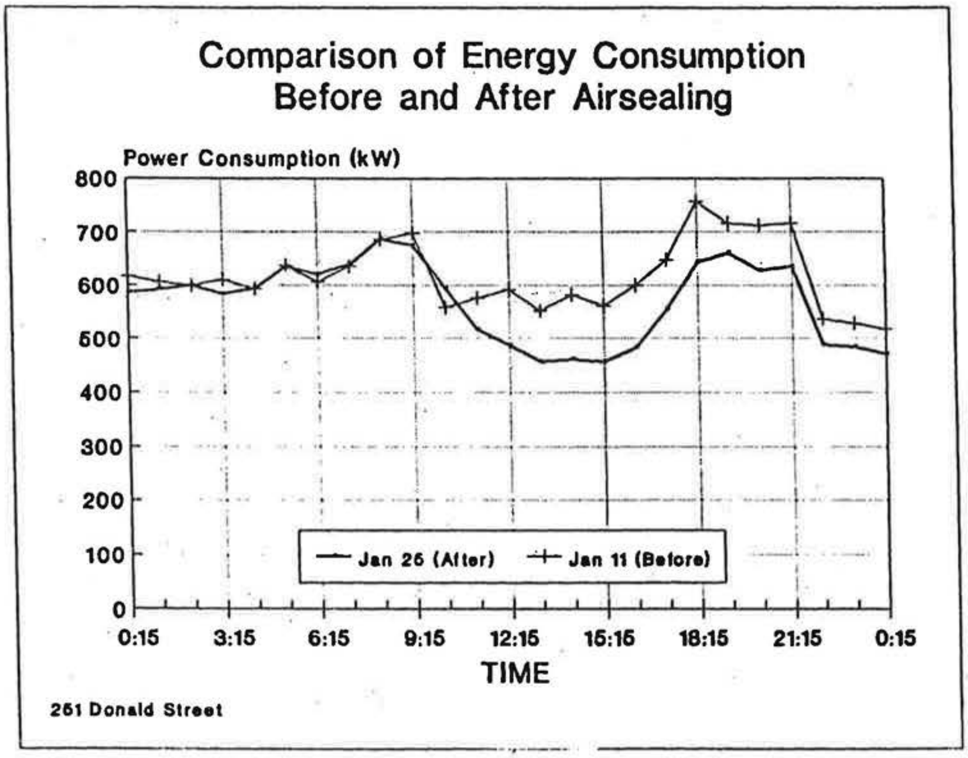


Figure 39: Comparison of peak demand.

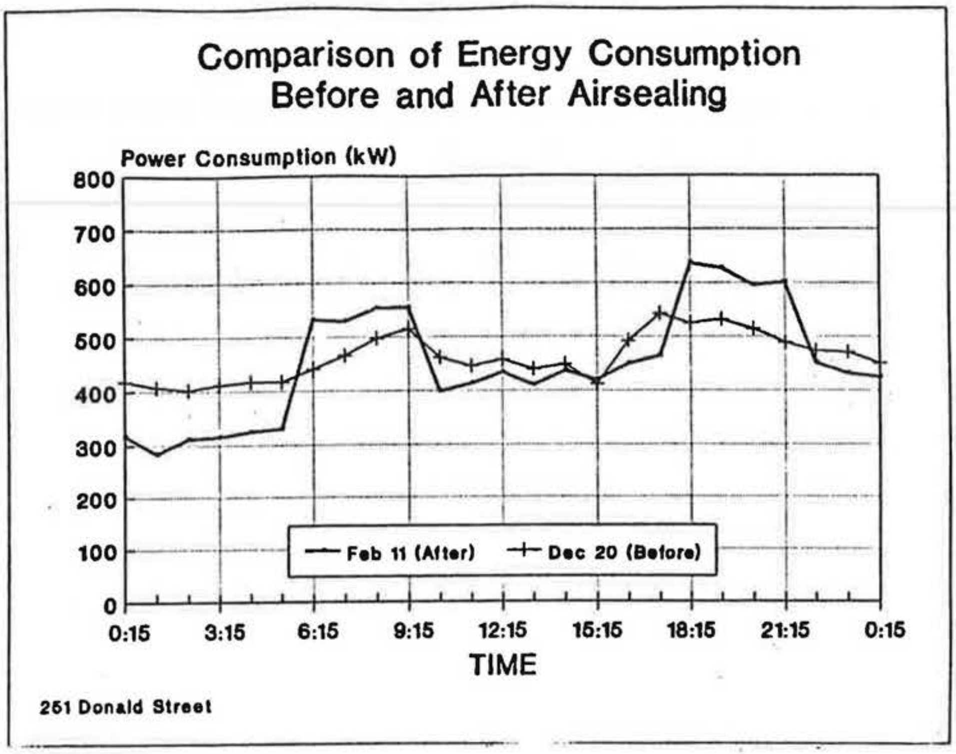


Figure 40: Comparison of peak demand.

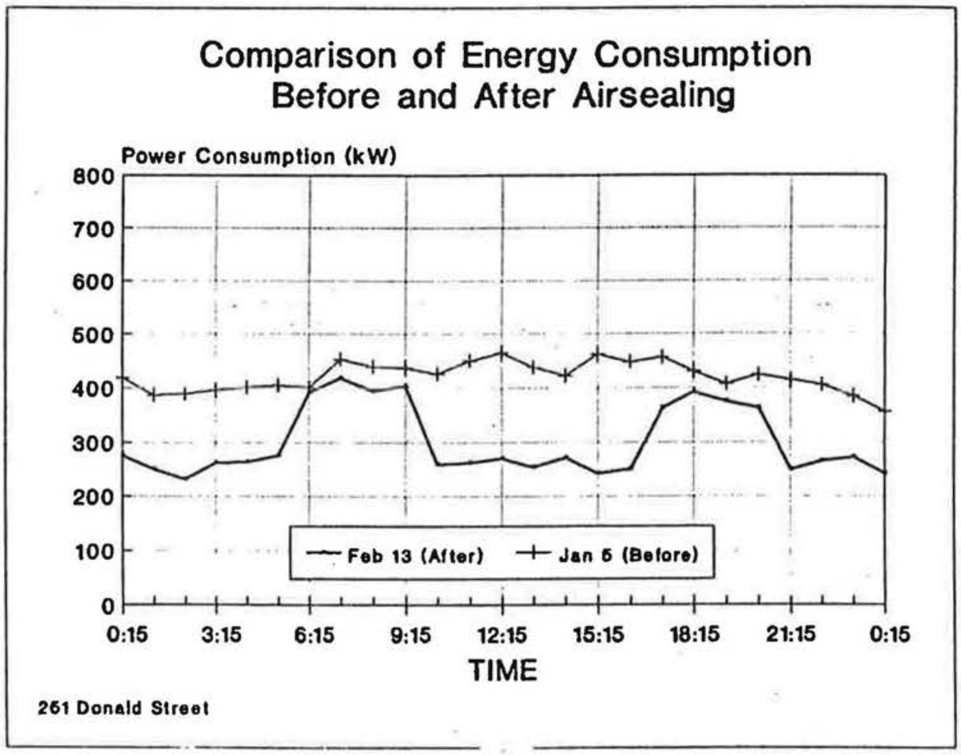


Figure 41: Comparison of peak demand.

3.5.3 Bridleview Building

Energy consumption in the Bridleview Condominium building in Toronto was continuously monitored at 15 minute intervals. The monitoring began on from November 22, 1990 to April 23, 1991. The total electrical load for the building and the ramp heating loads were monitored for a period of more than five months. The monitored data was analyzed to determine the effects of air-sealing on energy consumption.

The air sealing work in the Bridleview building was completed on December 21, 1990. The similar weather periods (ambient temperature and wind speed) between Nov 22 to Dec 10 (before air-sealing) and Dec 22 to Feb 28, 1991 (after air-sealing) were used to determine the effect of air-sealing on power consumption. Appropriate correction factors were used to account for solar gains (such as a December day is shorter than a January or February day) and weather effects.

Figures 42 to 54 show the profile of total electric demand and energy consumption for the building. These figures show the daily minimum and maximum electric demands and energy consumption.

For an assessment, the energy consumption before and after air-sealing was analyzed using the two sets of similar weather days. These sets were selected by observing the hourly weather data for Toronto as supplied by Environment Canada. These sets are as follows:

Table 13: Two sets of data used for the comparison of electric load.

Set	Day	Ambient Temperature (C)			Wind Speed (km/h)	Heating Degree Days
		Max	Min	Mean		
1	December 7	3.3	-2.1	0.6	18.8	17.4
	January 17	2.4	-1.7	0.4	18.1	17.6
2	December 14	-1.3	-12.3	-6.8	10.8	24.8
	January 10	-1.9	-11.4	-6.7	12.3	24.7

The hourly space heating loads were calculated using the building description, weather data and the operation schedules for December 7 and December 14. The building description and operation schedules were adjusted to match the measured mean energy consumption for these days. This procedure enabled the establishment of a "base case" for the building description before the air-sealing.

The further energy analysis for January 10 and January 17 was performed using the hourly weather data for those days with the same building description file. The energy consumption for January 10 and 14 (period after air-sealing) provided an approximate profile of electric loads on the building, assuming that the building was not air-sealed. The difference in the electric load on two "similar" days is generally due to solar gains and a difference in weather profile. This difference in electric load is used in correcting the actual load measurements for the building.

The comparison of electric loads is shown in Figures 50 and 51. The average difference in electric load before and after air-sealing is between 24 and 35 kW for the above mentioned days after applying proper corrections for the weather data. The reduction in space heating load is 9 to 12% of the electric heating demand (287 kW) -- or approximately 5 to 7.3% of the total peak electric load (481 kW) during the month of January.

A further analysis using the building description, and an assumed weather profile for a peak day (ambient temperature varying from -18 C to -21 C, and average wind speed of 24 km/hour) was simulated to predict the potential reductions in heating load. The reduction in heating load due to air-sealing would vary from 38 to 42 kW (approximately 7 to 9%) for this building on peak winter design days (calculated design electric load for such days may increase to 496 kW).

A simple comparison of monthly electric demands as assessed in the electric bills, as shown in Table 14, indicates that the air-sealing had a positive impact in reducing the monthly electric demands.

Table 14: Comparison of electric demand and monthly degree days (actual billing data).

Year	December		January		February	
	Electric Demand kW	Degree Days	Electric Demand kW	Degree Days	Electric Demand kW	Degree Days
1986	482	595				
1987	464	565			496	665
1988	496	645	496	699	480	718
1989	512	871	480	625	464	684
1990	451	587	528	583	448	603
1991			481	735	445	571

Comparison of Air-Sealing Assessment and Monitored Data

It was estimated that the peak heating electric load due to uncontrolled air leakage in building was approximately 71 kW for the Bridleview Building using the air-sealing assessment procedure. It was assumed that the air leakage rate would be reduced by 50% with air-sealing. The estimation method predicted a peak power reduction potential of 35 kW.

Comparison of predicted reductions in peak heating demand and the energy consumption measurements show comparable results. The predicted reductions in peak heating demand are less than 5% higher than the measured results.

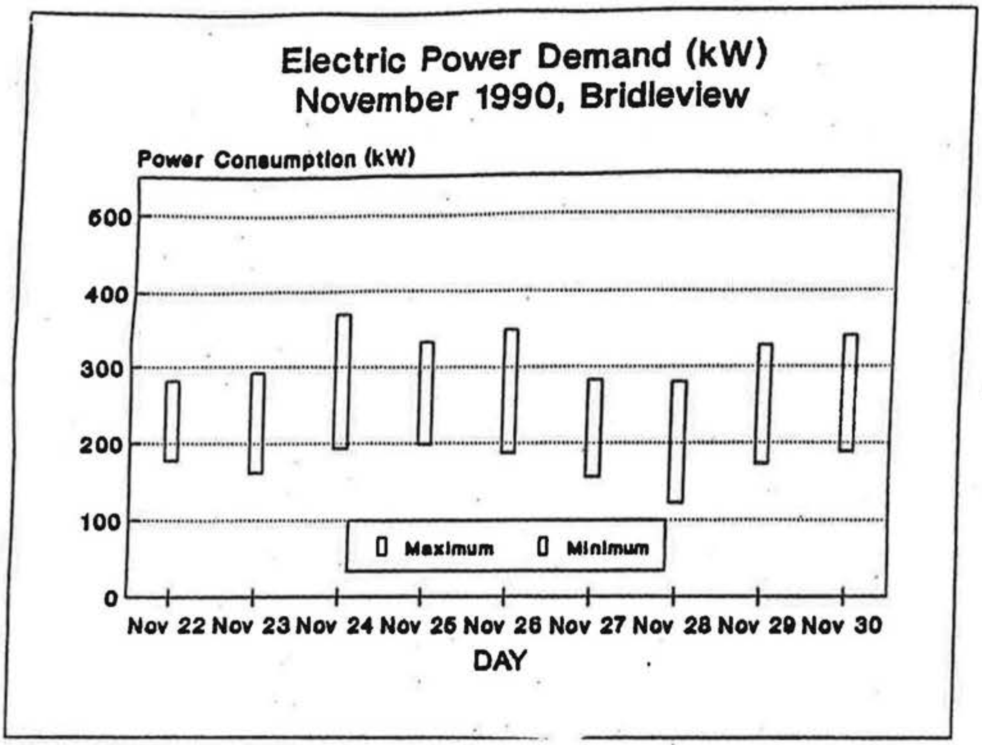


Figure 42: Daily electric demand - November 1990.

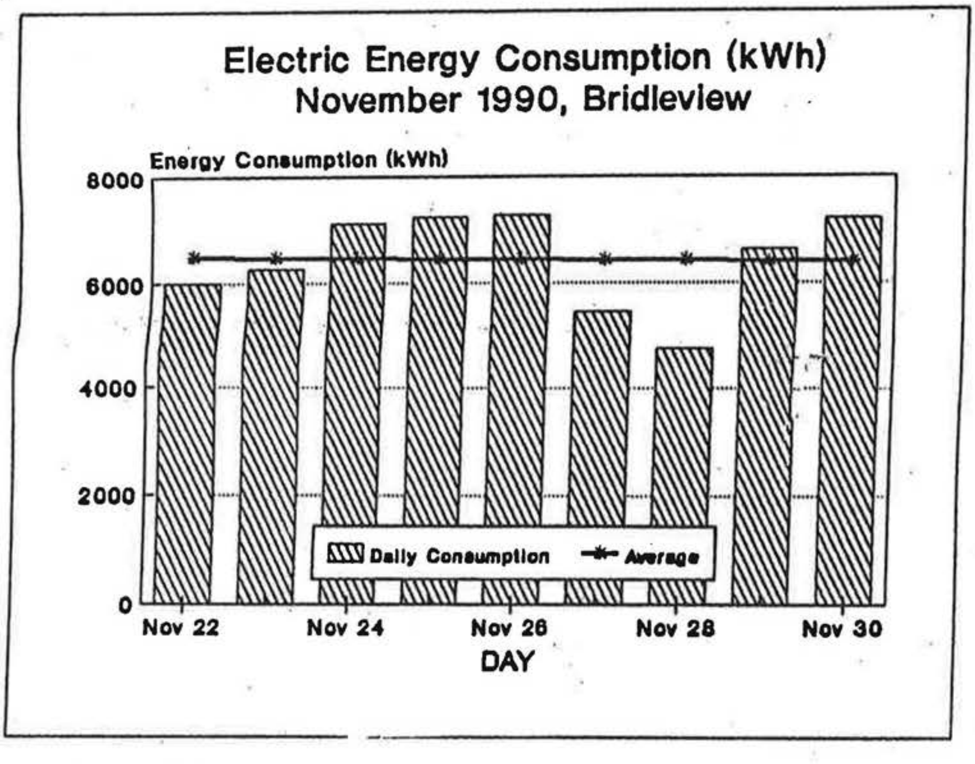


Figure 43: Energy Consumption - November 1990.

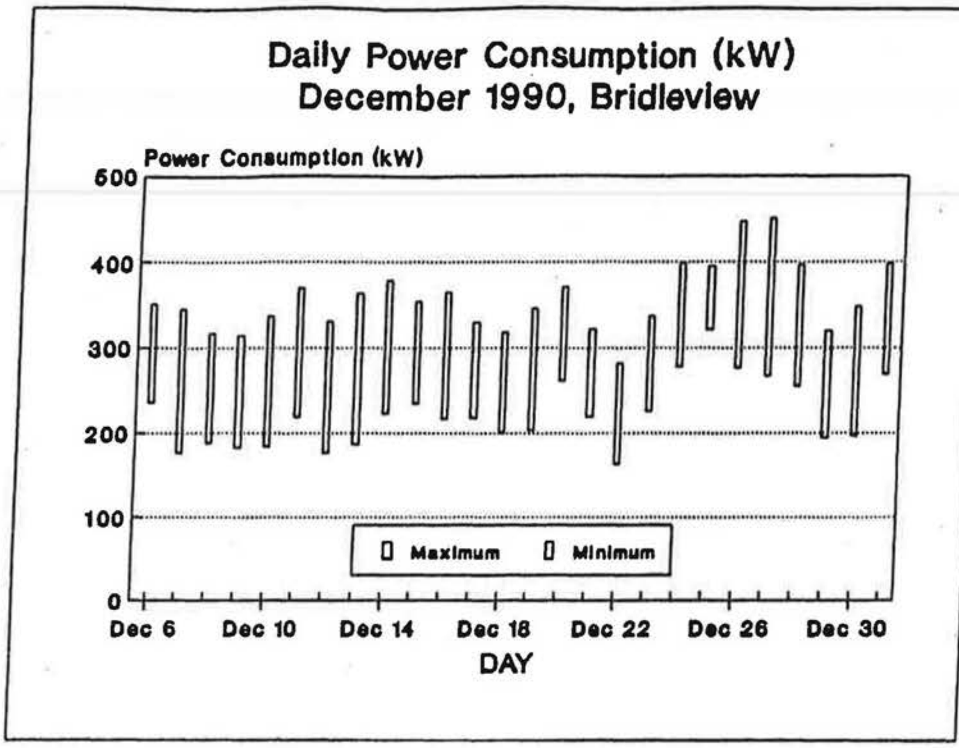


Figure 44: Daily electric demand - December 1991.

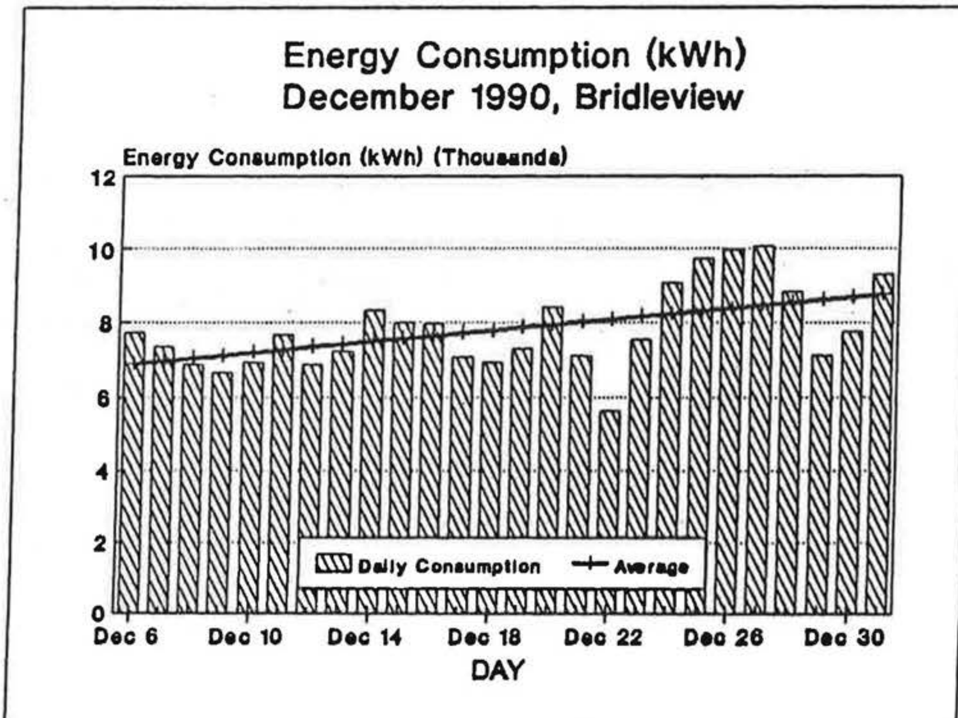


Figure 45: Energy Consumption - December 1991.

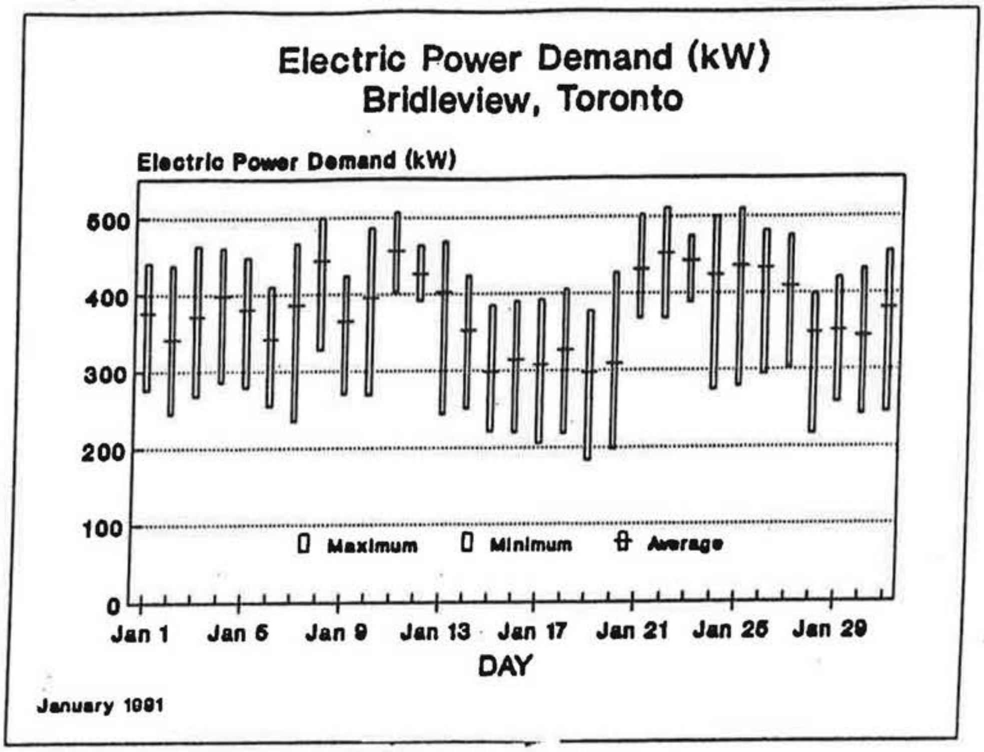


Figure 46: Daily electric demand - January 1991.

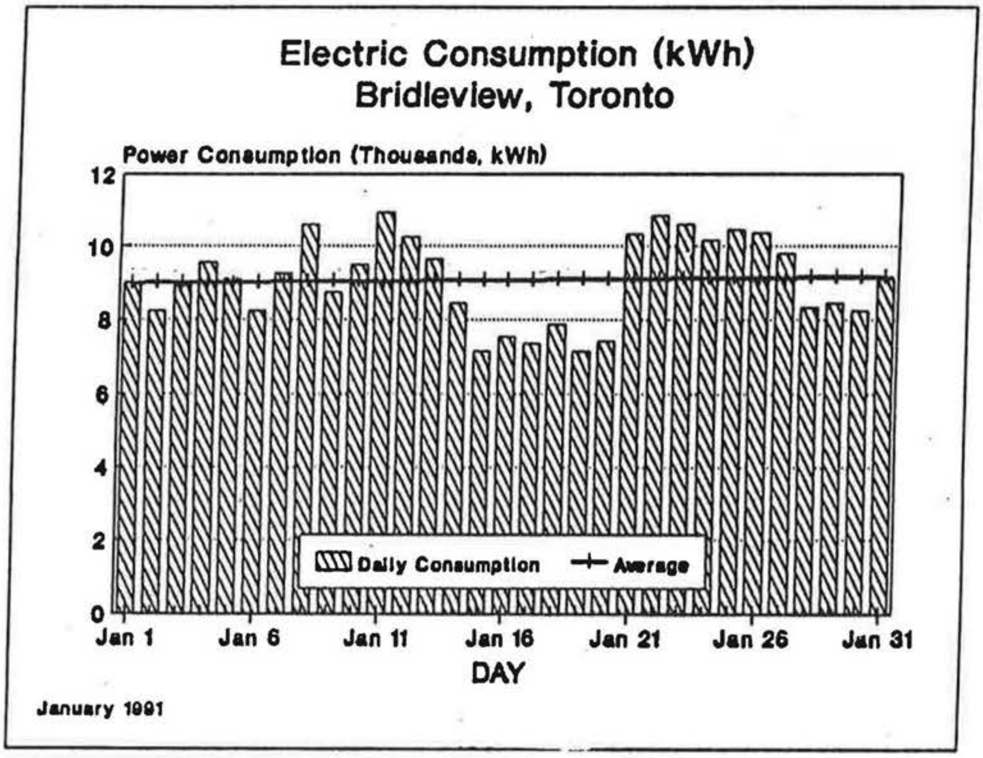


Figure 47: Energy Consumption - January 1991.

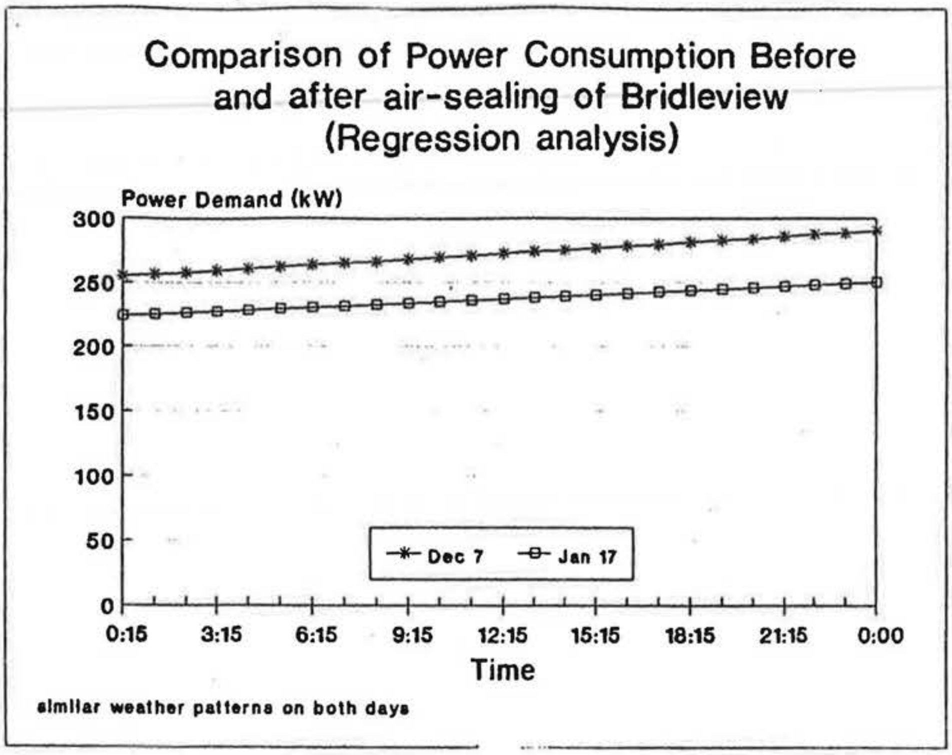


Figure 52: Comparison of peak demand at Bridleview building.

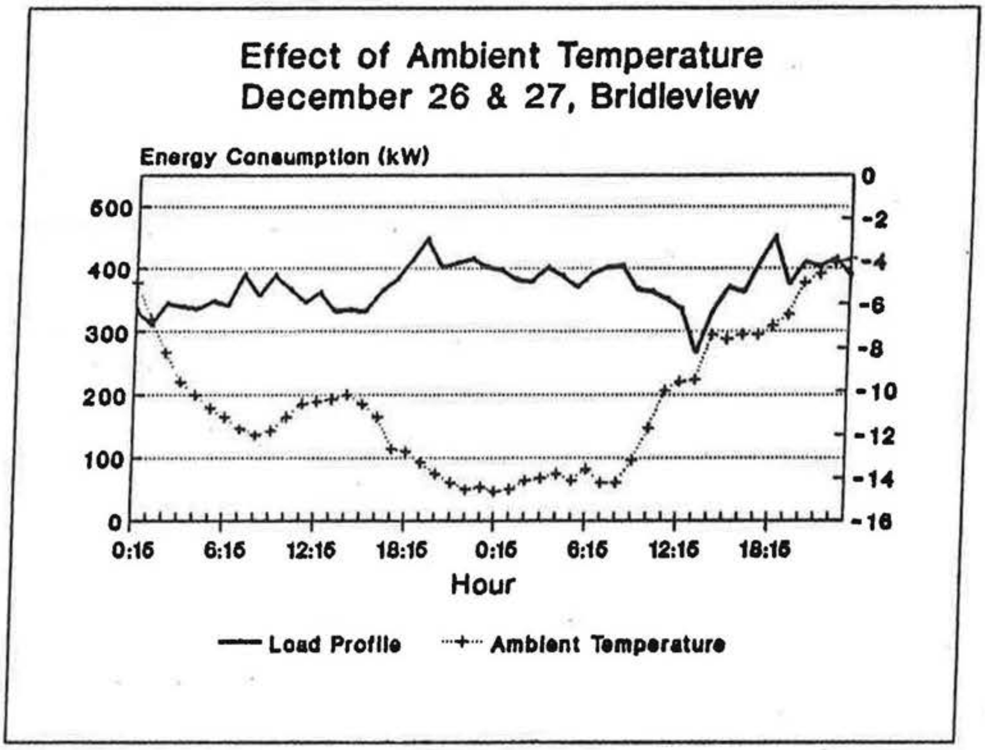


Figure 53: Effect of ambient temperature.

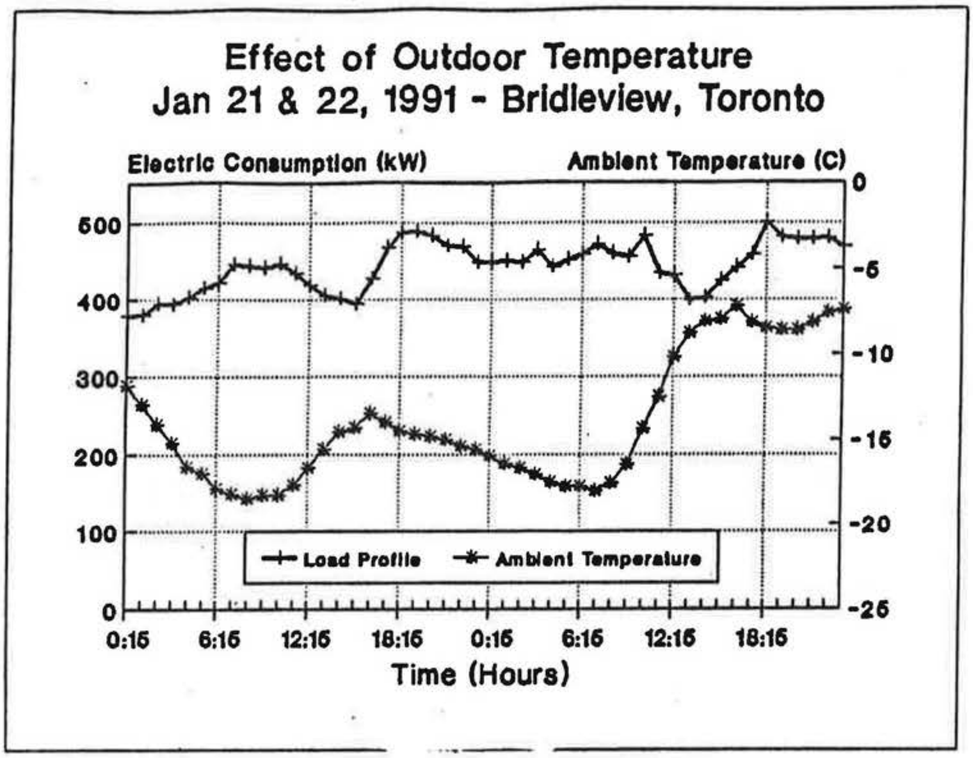


Figure 54: Effect of ambient temperature.

3.6 Sensitivity Analysis

The field data offers three to five different characteristics of air leakage paths: tight, fairly tight, average, loose and very loose. The characterization of building components in these five distinct groups may be non reproducible in many circumstances. It is quite easy to characterize the leakage path as tight, average or loose. But the intermediate categories, such as fairly tight and loose, may be difficult to decipher.

Sensitivity analyses were conducted using the field inspection data for the two test buildings. The building component leakage characteristics were altered between tight and average, and average and loose to evaluate the difference in the estimation of the air leakage rate for the building. The building auditor, in most cases, would be able to identify and characterize the proper leakage class. In cases where only some components may be difficult to assess for leakage class, the resulting difference due to such errors will contribute by less than five percent in the calculation of "net" air leakage rate. However, if the auditor assigns the incorrect leakage class to all building leakage paths, the difference in "net" air flow will be more than 40%. It is expected that with proper training, the auditors should be able to verify the leakage paths and assign appropriate leakage class.

3.8 Indoor Air Quality (IAQ)

Air quality in residential buildings is an area of great concern. With the trend to conserve energy, the effects on air quality should be evaluated to avoid potential health problems which may result from the drastic reduction in air change. Therefore, during this study, air quality tests to monitor the effects of the air sealing work were done before and after the air sealing.

It should be noted that the prime objective of this project was to evaluate the state of indoor air quality in high rise apartment buildings by grab samples and on-the-spot measurements to determine the impact of air sealing on occupants. The air quality portion of this project was designed as a simple verification to ensure that no air quality problems were created by the energy conservation measures implemented.

A total of eight (8) apartments were tested during the week from January 4th to 11th, 1991 to record the "before conditions" in 251 Donald street and the week of February 15th to 22nd, 1991 to measure the "after conditions". Some tests consisted of a one week monitoring while others were spot checks at the beginning and end of the monitoring periods.

The type of tests, test methods, number of apartments included in the air quality survey, selection of apartment location within the building etc. were all determined in order to provide the most valuable information at the best cost keeping in mind the objectives and budget allocated. CMHC's "Indoor Air Quality Test Protocol For High-Rise Residential Buildings" was the guide used for selecting the tests and test methods.

3.8.1 Tests Selected

Four elements were determined to be relevant in this building: carbon dioxide, formaldehyde, temperature, relative humidity, and radon.

Carbon Dioxide

In a building which has no combustion appliance, carbon dioxide (CO_2) is mostly produced by the occupants. CO_2 levels tend to vary according to the number of occupants in the apartment, ventilation practices (use of exhaust fans, opening of doors & windows etc.) and can vary at different times of the day based on the activity level and habits of the occupants. Long term monitoring studies have shown these variations track very well the occupancy of a room for instance. Continuous monitoring is the favoured way to capture these variations but also involves either very expensive equipment and/or the need for sophisticated dataloging equipment. In order to have measurements in all the apartments selected at a reasonable cost, it was decided to take spot measurements of CO_2 at the beginning of the monitoring week and at the end.

The test method used was the GASTEC pump with GASTEC Carbon dioxide (CO_2) tubes "extra low range" (300-5000ppm)

As much as possible, the carbon dioxide readings were taken at the same time to facilitate comparison between the two before air sealing readings, one against the other, as well as against the two after air sealing readings. Most readings were taken between 9am and 12pm.

Formaldehyde

Although the building does not contain any known large source of formaldehyde (such as insulation), this gas can usually be measured in most buildings from common sources such as: carpets, particleboard, household cleaning products, cigarette smoke etc. Since the sources which may be releasing formaldehyde would not change before and after the air sealing, the formaldehyde readings can be used to measure the effect on air change in the apartment.

The test method used for formaldehyde readings consisted of a monitoring device designed to provide an average concentration over a period of one week. Two Air Quality Research Institute's PF-1 formaldehyde monitors were installed in each of the apartments tested.

Humidity

Relative humidity (RH) usually increases as a result of air sealing work in buildings when no provisions are made to remove the moisture generated by normal activities.

The measurements of relative humidity were taken with a sling psychrometer (Taylor, 9", temp. range from 5 to 50°C) at each visit to the tested apartments (twice before air sealing and twice after). Furthermore, hygrothermographs were installed for a one week period in some apartments. These have recorded the temperature and relative humidity variations which occurred during the week.

Radon

Radon enters buildings through cracks in the foundation walls and floor slab and the highest readings are usually found in the basement. In this building there are no apartments in the basement and only the general meeting room above the slab-on-grade portion of the foundation. Grab sampling for radon was done in the basement and in the meeting room using the Pylon AB5

No radon readings were done in any of the eight apartments tested. Had high radon levels been detected in the basement or on the main level radon readings would have then been taken as a precautionary measure in some apartments.

Selection and Location of Test Apartments

The 251 Donald street building is a 21 storey, rectangular building with the majority of apartments facing either due east or due west. There are two north facing and two south facing apartments per floor.

The apartments tested were selected on the following basis:

- Equal number of apartments on the east and west sides of the building. (to capture differences due to winds "windward/leeward" effects if any)
- Apartments facing each other on the selected floors. (so that both apartments are the same distance away from the fresh air distribution in the corridor)
- Apartments with the least amount of exterior wall (worst possible condition where there is less exterior

wall to allow incidental fresh air infiltration)

- Two apartments on the lower floor, two on the top floor, two at mid height below the neutral pressure plane and finally two at mid height above the neutral pressure plane. (to detect differences due to the stack effect)

Although it was recognized that some factors had to be limited to facilitate the interpretation of results in such a small survey, no pre-requisites were set for the occupancy or lifestyles of the occupants. This was intended to provide some randomness in the IAQ survey.

The apartments selected were numbers 07 and 10 on the 2nd, 8th, 15th and 22nd floors. These units were the farthest from the fresh air ventilation grill in the corridor (corner units excepted). The doors to these east and west side apartments were directly opposite from each other.

<u>Occupants</u>

Amongst the selected apartments, two had a double occupancy while the rest had only single occupancy. One of the apartment's occupant was away during the entire period from December till the end of February. This vacant apartment has served as a control unit to some extent where occupant's habits did not affect the test conditions. Measurements in that apartment are all resulting from the effects of the air sealing work alone and resulting building dynamics.

There were only two smokers out of all the occupants involved (One cigarette smoker, the other a pipe smoker). All occupants did spend most of the time indoors all day. Besides the apartment which remained unoccupied during the entire testing periods, one other occupant was away for three days at the beginning of the January test period.

<u>Weather Conditions</u>

In order to eliminate as much as possible any variations other than the effect of the air sealing, the air quality tests were done during periods of similar seasonal conditions. Before and after air sealing air quality tests were done immediately before and after the sealing work to monitor similar winter indoor conditions. This is the time of year when the lowest amount of fresh air is provided from the opening of windows and balcony doors. Fresh air is then only supplied by incidental air leakage through the building envelope and supposedly by the fresh air supply fan in the corridors of the building.

The test periods selected were both very cold with mean temperatures during the period from Jan.4 to 11 at -13.4°C with average winds at 15.35 km/h and from Feb. 15 to 22 at -7.0°C with winds at 17.2 km/h.

3.8.2 Test Results

In general, only minor changes were noticed with regards to the air quality in the apartments tested. Despite the relatively small sampling, valuable information was collected to confirm expected trends which result from such air sealing work.

Carbon Dioxide

Donald Street Building: The carbon dioxide levels either remained the same or decreased slightly in some apartments after the air sealing. The average of all readings before air sealing was 862.5 parts per million (ppm) and 787.5 ppm after. The range of concentrations encountered varied from a low of 400 ppm to a high of 1500 ppm.

Bridleview Building: The carbon dioxide levels either remained the same or decreased slightly in some apartments after the air sealing. The average of all readings before air sealing was 800 parts per million (ppm) and 700 ppm after. The range of concentrations encountered varied from a low of 400 ppm to a high of 900 ppm.

Although CMHC's protocol mentions that "CO_2 levels in most areas would not be expected to build up to the 800 - 1000 ppm range common in offices", numerous indoor air quality surveys in residential buildings have shown that it is quite frequent that CO_2 reaches as high as 1300 to 1500 ppm. Therefore, the readings of CO_2 found in this building are quite within the norm and well below Health and Welfare's maximum level of 3500 ppm.

Relative Humidity

Donald Street Building: The relative humidity levels increased in the lower floor apartments and decreased in the upper apartments. One apartment had high RH readings both before and after the air sealing. The RH levels were at 45 and 46% before and 46 and 38% after air sealing. There was lots of condensation on the windows in this apartment. It should be noted that this was one of the apartments with two occupants. In any case, despite the concerns about the RH levels in this apartment, the RH did not increase after the air sealing. The average RH was at 29.5% before and 31.5% after.

Bridleview Building: The relative humidity levels increased in the lower floor apartments and decreased in the upper apartments. The average RH was at 24% before and 32% after air sealing.

Health and Welfare Canada suggests that RH levels be maintained between 30 to 55% in the winter and 30 to 80% in the summer. These are within the Health and Welfare guidelines but are somewhat high for what is usually recommended in house with only double glazed windows in the winter.

Formaldehyde

Donald Street Building: All formaldehyde concentrations were well below 0.06 parts per million. The formaldehyde readings did increase slightly in the two second floor apartments after the air sealing while they remained relatively the same in the other cases. This slight formaldehyde increase in the lower floor apartments is consistent with the slight rise in relative humidity. Both indicate that the air sealing work was effective in reducing the air infiltration on the lower floors while increasing comfort (Higher RH) and without creating an air quality problem (still low formaldehyde levels).

The average formaldehyde concentration was 0.024 ppm before sealing and 0.025 ppm after. The test series after air sealing had three location where the formaldehyde was not detectable or less than 0.01 ppm. A 1981 survey of formaldehyde in Canadian houses (not insulated with urea formaldehyde insulation) had shown an average concentration of 0.037 ppm.

One apartment had average formaldehyde readings of 0.062 ppm both before and after the air sealing work. This was also the apartment with the highest relative humidity readings. It should be noted that any materials that do off-gas formaldehyde will do so to a greater extent in humid conditions.

The lower CO_2 and formaldehyde levels found in apartment # 2207 after the air sealing could simply be due to the fact that the occupant in that apartment does open the windows and the balcony door as often as the weather allows. This occupant likes to keep the apartment cool and always has the thermostats turned to the lowest setting.

Bridleview Building: All formaldehyde concentration readings were below 0.05 ppm. The formaldehyde readings did increase slightly in the two second floor apartments after the air sealing while they remained relatively the same in the other cases. This slight formaldehyde increase in the lower floor apartments is consistent with the slight rise in relative humidity. Both indicate that the air sealing work was effective in reducing the air infiltration on the lower floors while increasing comfort (Higher RH) and without creating an air quality problem (still low formaldehyde levels).

Radon

Donald Street Building: Radon testing at the beginning of January showed very low radon levels. The average radon reading in the mechanical room in the basement was 8.79 Bq/m^3 (0.24 pCi/L) and 20.05 Bq/m^3 (0.54 pCi/L) in the recreation room on the main floor. Post air sealing radon were measured using the "Electrets", one week monitors. The average radon reading in the mechanical room in the basement was 9 Bq/m^3 (0.25 pCi/L) and 22 Bq/m^3 (0.58 pCi/L) in the recreation room on the main floor. The change in radon level before and after air sealing was insignificant.

Bridleview Building: Radon testing at the beginning of month of December showed very low radon levels. The average radon reading in the mechanical room in the basement was 9.5 Bq/m^3 and 6 Bq/m^3 in the common room on the main floor. Post air sealing radon reading in the mechanical room in the basement was 9.5 Bq/m^3 and 7.5 Bq/m^3 in the recreation room on the main floor. The change in radon level before and after air sealing was insignificant.

Health and Welfare Canada's maximum acceptable level for radon is 800 Bq/m^3 (22 pCi/L). The United States very conservative maximum acceptable level is 148 Bq/m^3 (4 pCi/L). The radon readings detected in this building were much lower than both of these set guideline maximums.

Discussion

The air sealing has had no negative impact on the general indoor air quality in the building. Variations from apartment to apartment shown are quite representative of what could be expected due to the occupants' lifestyles and habits.

Figure 54: Typical floor layout of Donald Street building.

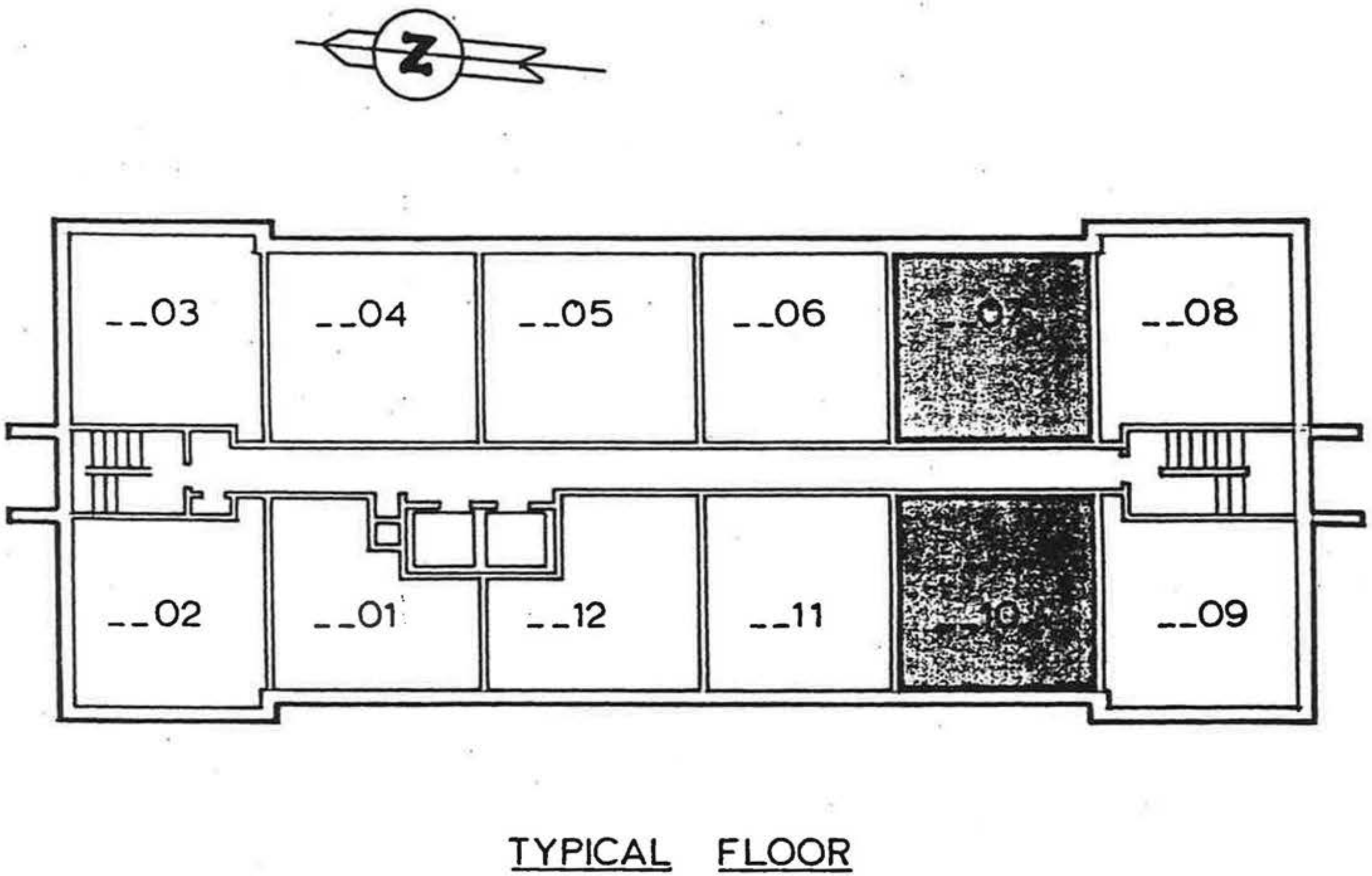


Table 16: Measurements of formaldehyde concentration in Donald Street building.

251 Donald Street

Formaldehyde

Formaldehyde Testing Method: AQR, PF-1 Formaldehyde Monitors

Sampling Dates		Jan 4 – 11, 1991		Feb 15 – 22, 1991		Degree of Change
		Concentration		Concentration		
			Average		Average	
Sampling Location		(ppm)	(ppm)	(ppm)	(ppm)	
Apt # 207	living room	0.015	0.016	0.025	0.031	slight increase
	master bedroom	0.016		0.037		
Apt # 210	living room	0.013	0.016	0.036	0.034	slight increase
	master bedroom	0.018		0.031		
Apt # 807	living room	0.028	0.027	0.020	0.021	relatively unchanged
	master bedroom	0.025		0.021		
Apt # 810	living room	0.011	0.013	<0.01	0.008	relatively unchanged
	master bedroom	0.015		0.016		
Apt #1507	living room	0.018	0.019	0.019	0.020	relatively unchanged
	master bedroom	0.020		0.020		
Apt #1510	living room	0.064	0.062	0.061	0.062	unchanged
	master bedroom	0.059		0.063		
Apt #2207	living room	0.030	0.030	<0.01	0.000	decreased
	master bedroom	0.029		<0.01		
Apt #2210	living room	0.008	0.010	0.018	0.020	relatively unchanged
	master bedroom	0.012		0.022		

All of these readings are lower than Health and Welfare Canada's suggested maximum acceptable limit of 0.1 ppm.

Table 17: Measurements of carbon dioxide at Donald Street building.

Test Dates	January 1991			February 1991			% Change
	Jan. 4	Jan. 11	Average	Feb. 15	Feb. 22	Average	
Sampling Location	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	
Apt # 207 living room	900	500	700	600	500	550	-21.43
Apt # 210 living room	800	1000	900	800	1000	900	0.00
Apt # 807 living room	1300	900	1100	1000	1000	1000	-9.09
apt # 810 living room	800	1000	900	800	1000	900	0.00
Apt #1507 living room	600	400	500	500	500	500	0.00
Apt #1510 living room	1100	1500	1300	1300	1000	1150	-11.54
Apt #2207 living room	600	1000	800	900	600	750	-6.25
Apt #2210 living room	500	900	700	600	500	550	-21.43

Table 18: Measurements of relative humidity at Donald Street building.

Test Dates	January 1991			February 1991			% Change
	Jan. 4	Jan. 11		Feb. 15	Feb. 22		
Sampling Location	%	%	Average	%	%	Average	
Apt # 207 living room	26	27	26.5	25	30	27.5	3.8
Apt # 210 living room	23	25	24.0	29	34	31.5	31.3
Apt # 807 living room	35	26	30.5	30	33	31.5	3.3
apt # 810 living room	28	24	26.0	27	38	32.5	25.0
Apt #1507 living room	32	21	26.5	24	24	24.0	-9.4
Apt #1510 living room	45	46	45.5	46	38	42.0	-7.7
Apt #2207 living room	21	17	19.0	36	30	33.0	73.7
Apt #2210 living room	31	45	38.0	28	27	27.5	-27.6

3.9 Make-up Air Balancing

As identified in the assessment procedure, there is a need to re-balance the make-up air supply to each floor after air sealing of the building to gain proper distribution of fresh air supplied to each storey. In both buildings, make-up air balancing and tuning was undertaken just after the air sealing work. Appendix E contains a brief report on make-up balancing of both the Donald Street and Bridleview buildings.

As shown in Figure 55, in the Donald Street building, the corridor air flow on a floor varied from 110 to 340 L/s. The designed air flow for each floor is 285 L/s (600 CFM). The balancing and tuning of diffusers on each floor obtained the more or less constant air flow of 285 L/s on each floor. The balancing of air-flow also assists in maintaining ventilation required for each apartment.

In the bridleview building, the make-up air system is designed to provide 330 L/s on each floor. Before balancing, the flow per floor varied from 240 L/s to 410 L/s. Tuning of diffusers on each floor has achieved a more uniform flow of 320 to 340 L/s.

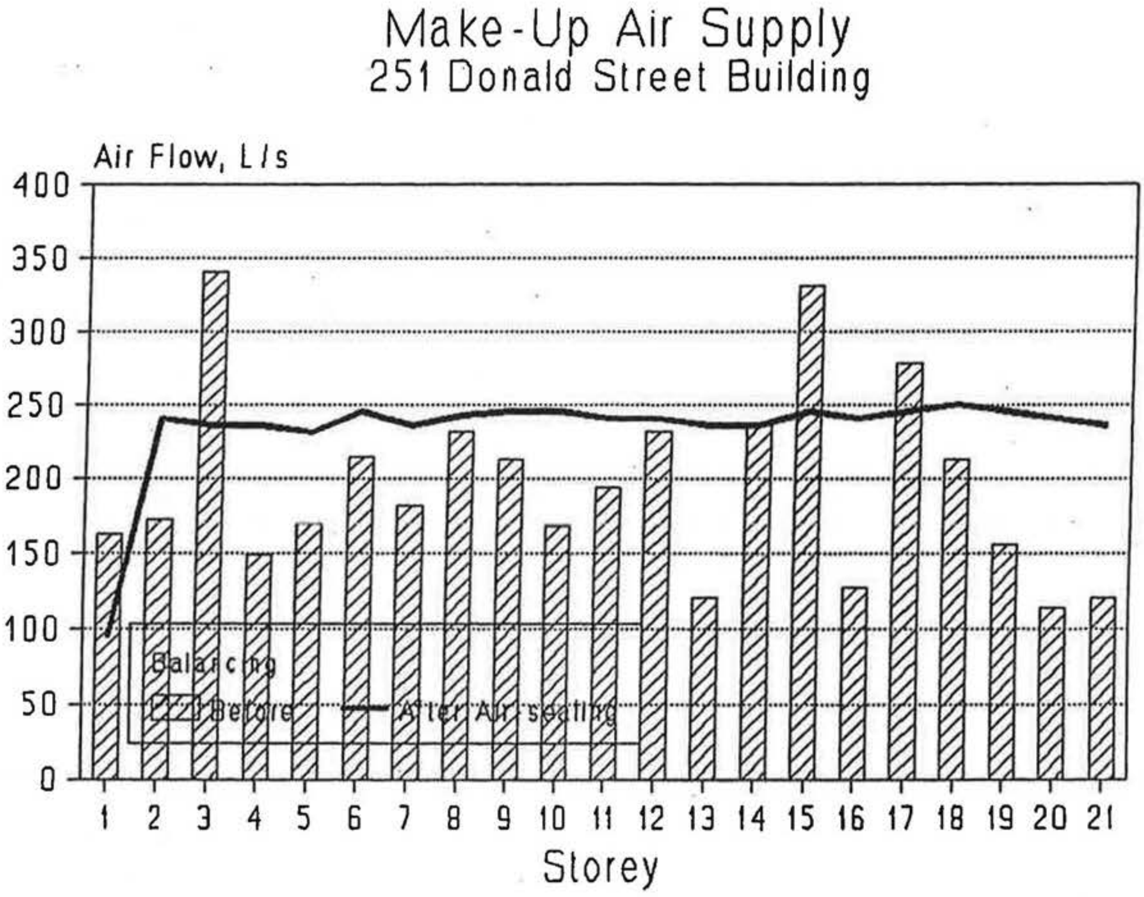
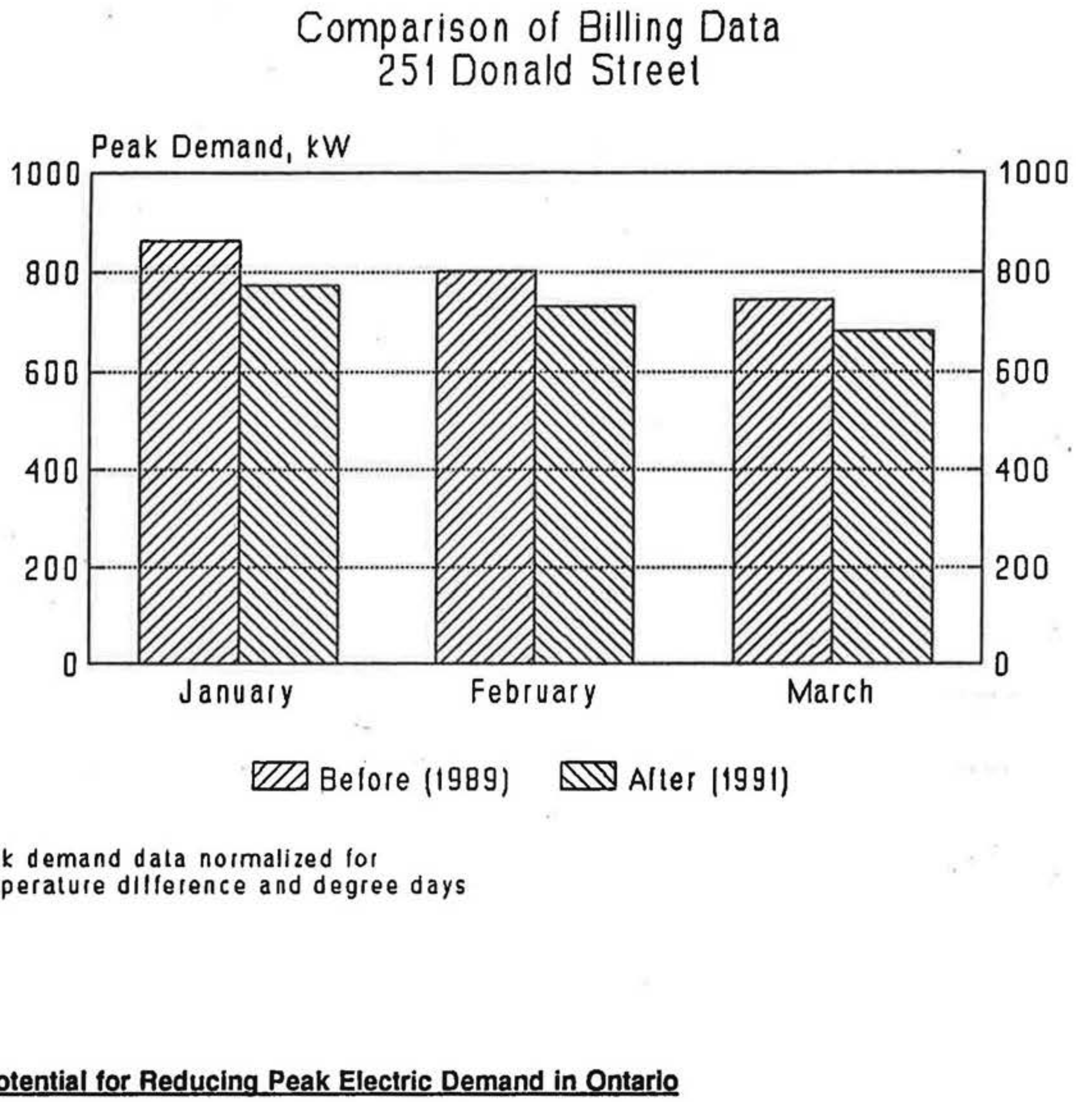


Figure 55: Make-up air balancing and tuning at Donald Street building after air sealing.

3.10 Comparison of Actual Billing Data for Donald Street Building

The impact of any energy conservation measure can be readily measured by comparing the monthly billing data before and after the implementation of such a measure. For a quick and definitive view, the project team gathered the actual billing data for winter months scanning through monthly electric bills. These data is plotted on Figure 56. As shown, the air-sealing has achieved the desired reductions in peak heating demand and energy consumption.



Peak demand data normalized for
temperature difference and degree days

3.11 Potential for Reducing Peak Electric Demand in Ontario

Ontario has more than 18,000 high-rise residential buildings comprising 76.3 million square metre of floor area. About 39% of these buildings use electricity as a main space heating fuel. Energy audit of several of these electrically heated building has shown that there is a significant potential for improving the space heating energy efficiency in these buildings. As shown in Section 1, energy audits and assessments of four high-rise buildings (10 to 22 storeys) in Ontario showed that the peak space heating demand varies from 35 to 65 W/m² of floor space. During peak winter conditions, the air leakage component contributes to the heating load by 10 to 18 W/m² - roughly 25 to 35% of the peak heating demand. Therefore, the control of air leakage has become recognized as a key element in achieving energy conservation. Concerned especially with reducing peak power demand, Ontario Hydro is exploring air leakage control of high-rise buildings as a component of its DSM strategy.

To evaluate the potential impact of a DSM program aimed at air leakage control of high-rise buildings, the potential peak electric demand and energy consumption was determined using the following assumptions:

- about 65% of high-rise buildings are located in the 4200 degree days region with the winter design temperature of -13°C;
- other 35% of high-rise residential buildings are located in the degree days above 4200 with the winter design temperature of -20°C;
- about 40% of buildings are all electric (space heating and make-up air heated with electric), and remaining buildings use electricity for space heating but use the fossil fuel for heating the corridor make-up air;
- the cycling factor of 0.6 was assumed (the cycling factor is defined as the ratio of simultaneous occurrence of peak electric demand in all buildings to the sum of total peak electric demand of all buildings).
- the commercial air sealing work can be effective in reducing the air leakage by 35%.

Based on these assumptions, Table 19 provides the summary of potential energy and peak power demand savings which can be obtained through air-sealing all electrically heated high-rise residential buildings. There is a potential to reduce 191 MW of peak electric demand by air-sealing all of Ontario's high-rise residential stock.

Table 19: Potential energy and peak demand savings due to air leakage control in Ontario.

	Total Floor Area* (Mm²)	Electric Heated*		Air Leakage Contribution		Potential Reductions about 35% sealing	
		%	Area m²	Energy GWh	Peak Demand MW	Energy GWh	Peak Demand MW
High-rise Residential	76.3	39	29.76	833	545	292	191
Detached, medium rise and row houses	142	24	34.08	1,091	896	382	314
Total potential reduction with @ 35% sealing equivalence:						674	505

* Using Building Stock Model - CANADA-II, Prepared by Scanada Consultants Limited for Energy, Mines and Resources Canada, 1990.

3.12 Summary

Two buildings were selected for the demonstration of air-sealing work. First, the estimation of air leakage rates was performed using the assessment procedure. Based on these estimations, air-sealing priorities were determined and the work plan for the air sealing was developed. The estimation method showed that there was a potential for reducing the peak electric demand of 96 kW in the Donald Street building, and of 49 kW in Bridleview building.

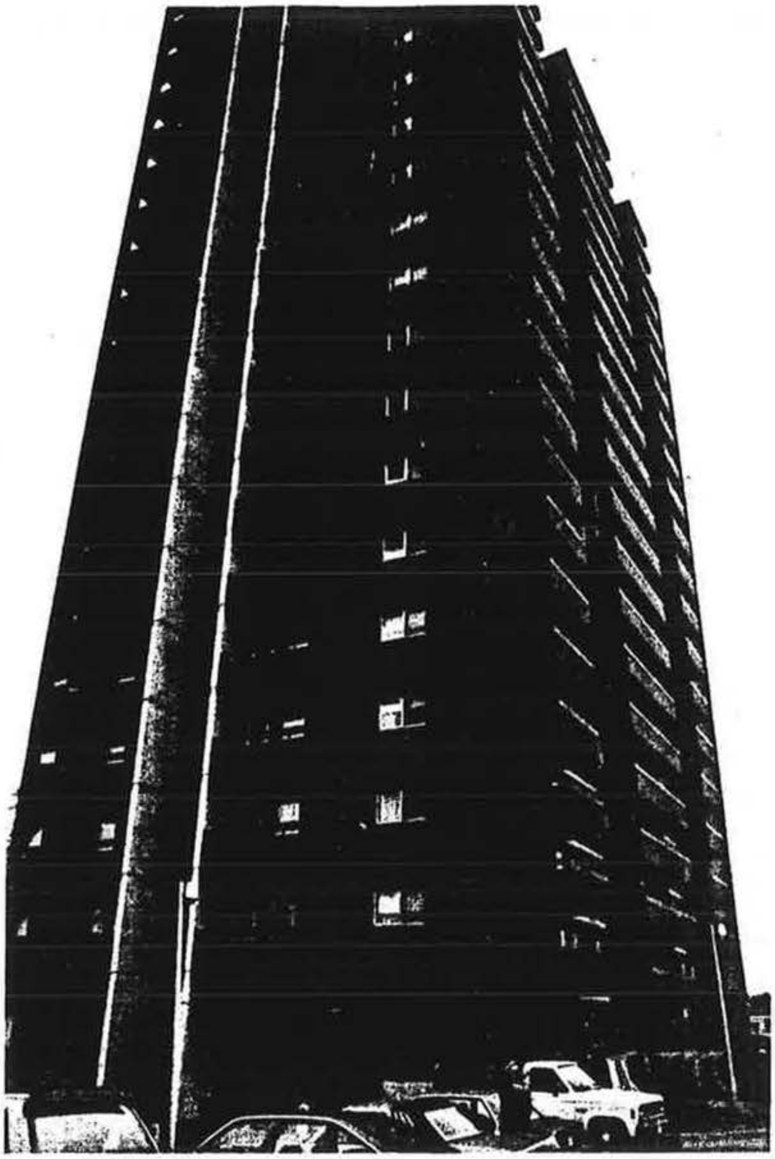
The fan tests were conducted to determine the "before and after air-sealing" improvements in the building envelope airtightness. Based on airtightness results, the peak heating demand was calculated.

The continuous monitoring of energy and power consumption in these two building for the winter months showed the following: The peak demand reduction in the Donald Street building was 85 kW, and in the Bridleview building it was 42 kW.

Based on these monitored results, the air leakage assessment procedure was modified and calibrated to reflect the practical aspects regarding the airtightening of buildings. A good air-sealing of a building would reduce the air leakage rate by 30 to 40%. The assessment method can predict the potential savings in energy consumption within 5 to 15%.

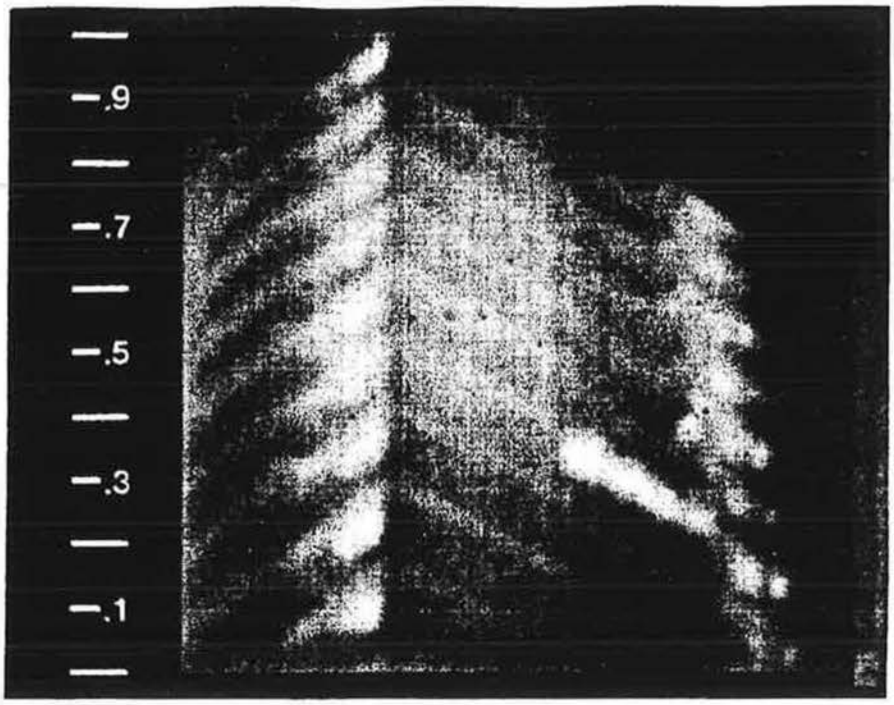
Cost-benefit assessment showed that the average cost of air-sealing varied from $645 to $880 per kW of demand reduction. The sealing of elevator shafts, garbage chutes and stairways was the most cost effective in both buildings. The second ranking was exterior envelope leaks, windows and doors.

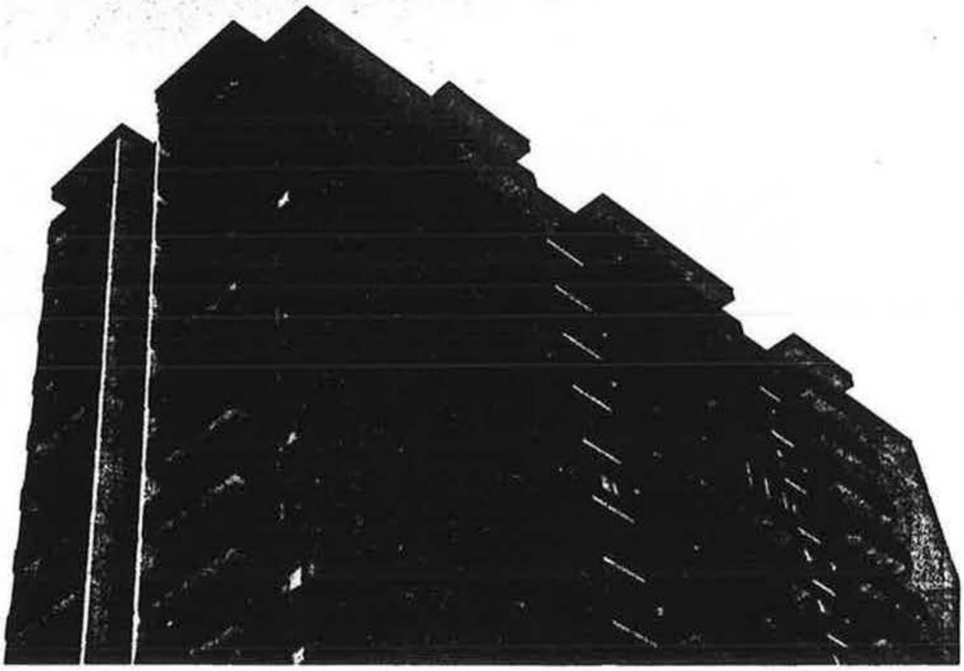
Indoor air quality tests showed that the air sealing of the building has no negative impact on the general conditions of comfort and air quality in both buildings. In Bridleview building, it was observed that air sealing has reduced the movement of stale odours.



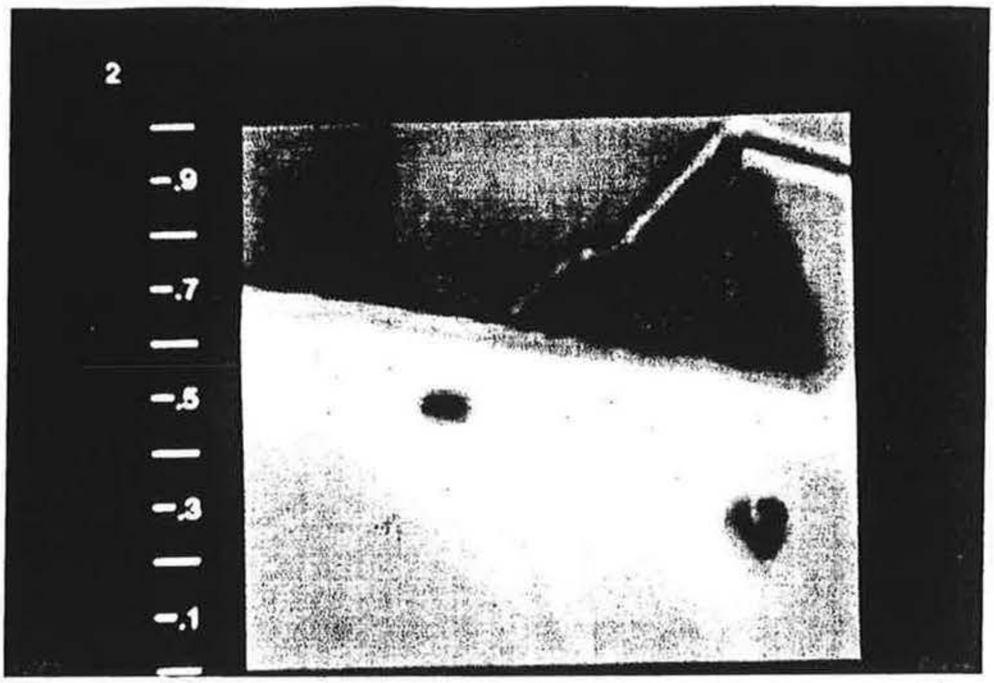
A 21 storey building in Ottawa was selected for the air leakage control demonstration project. The heating system is all electric, electric baseboards throughout the building as well as electric heating of the corridor make-up air.

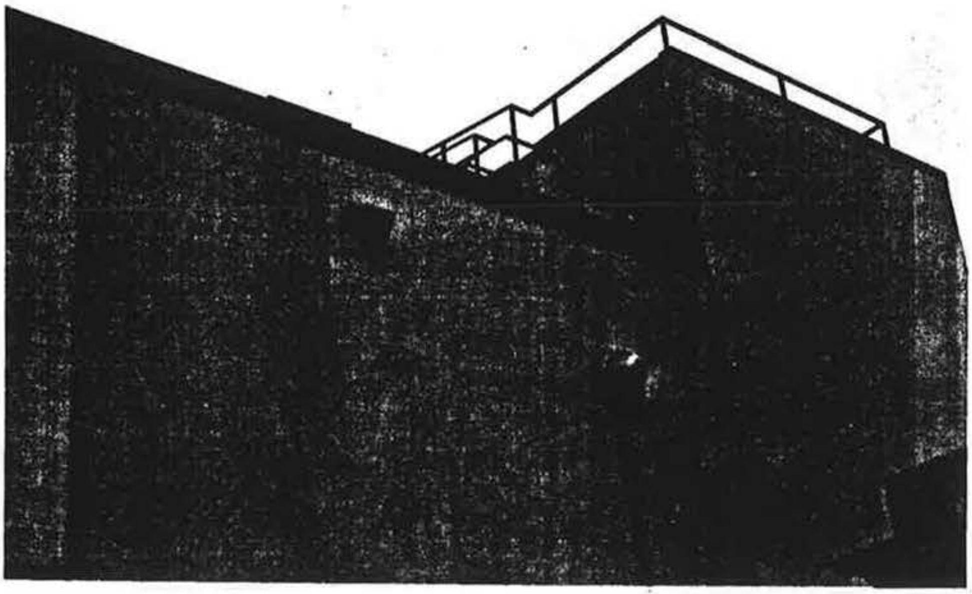
In Toronto, a 10 storey condominium building was selected for the project. This building is also heated with electric baseboards but the corridor make-up air is heated with natural gas.



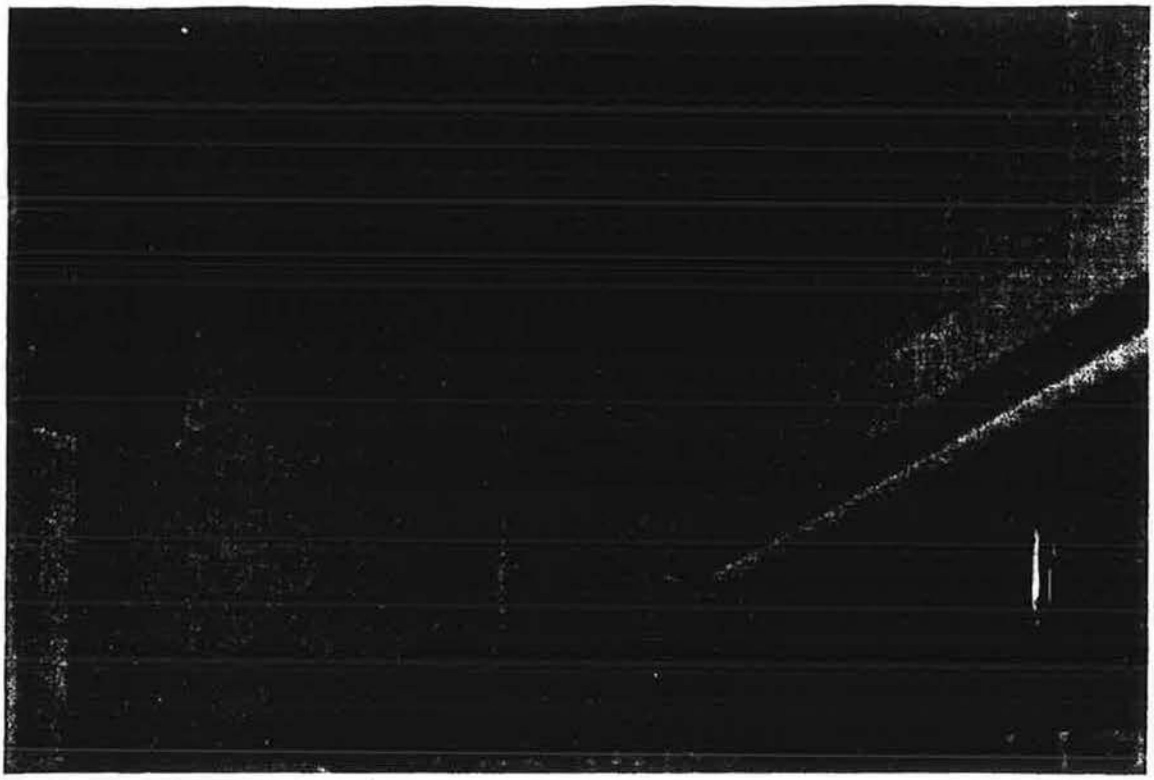


Infrared thermography was used to assess the air leakage and to determine if the building was free from major moisture problems.

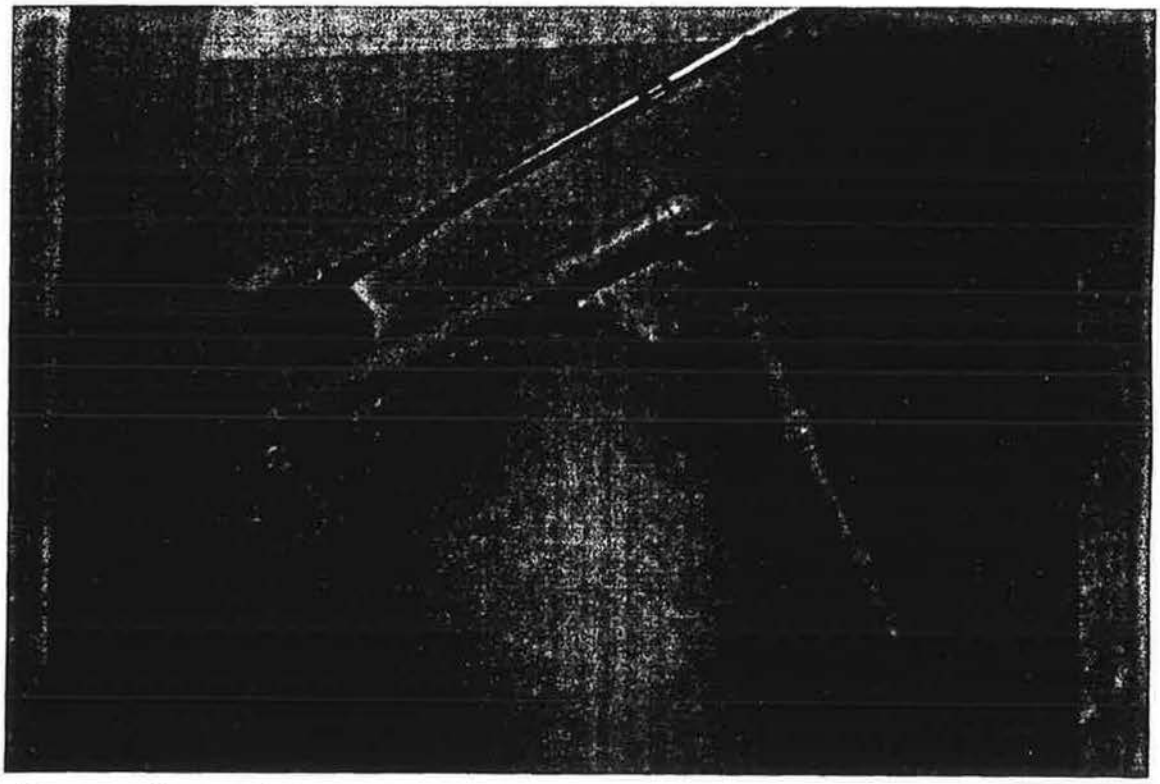




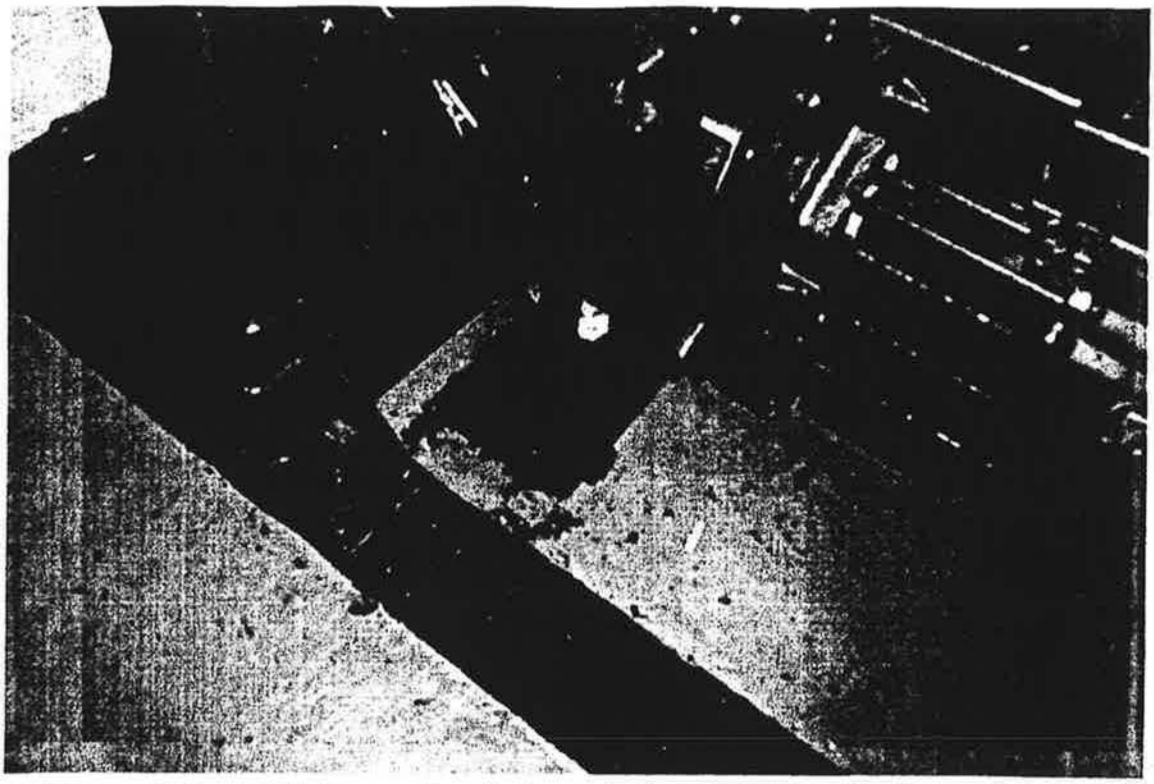
Exfiltration at the top of the penthouse's wall/roof joint is shown clearly with infrared thermography.



Dust markings are good tell tales of air leakage paths.

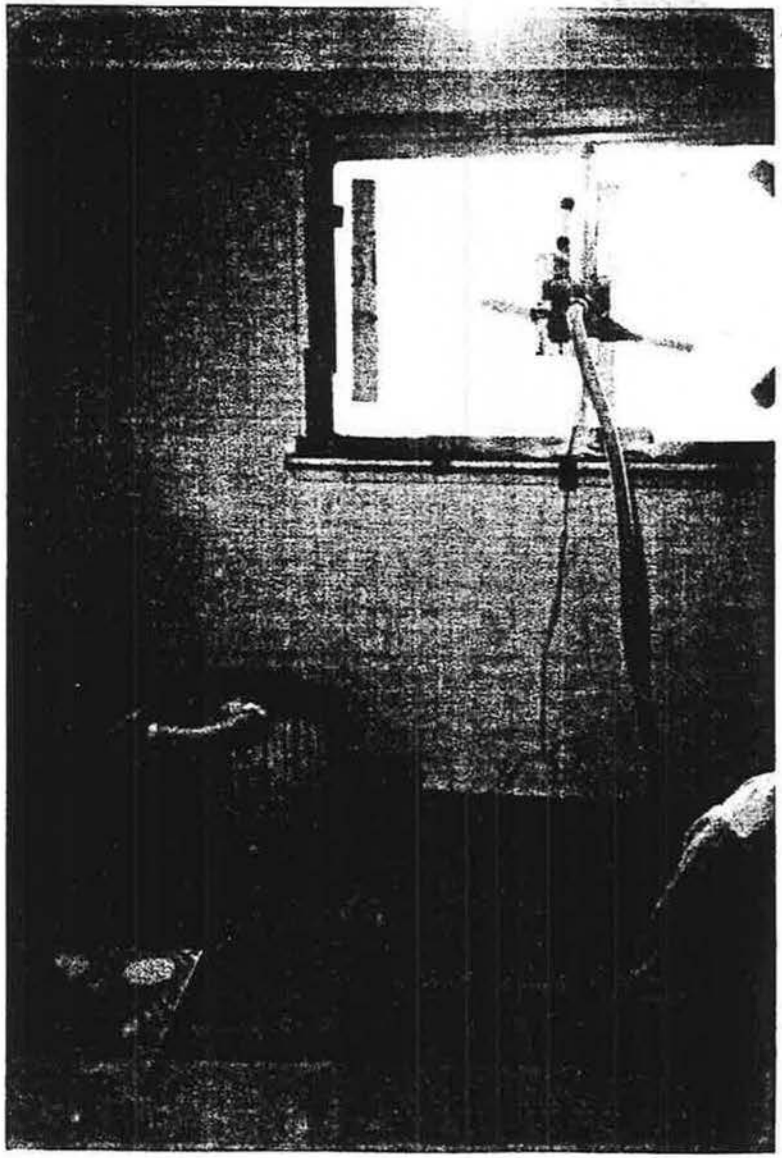


Bottom and top of shafts, such as this garbage chute, which run through the full height of the building must be looked at.

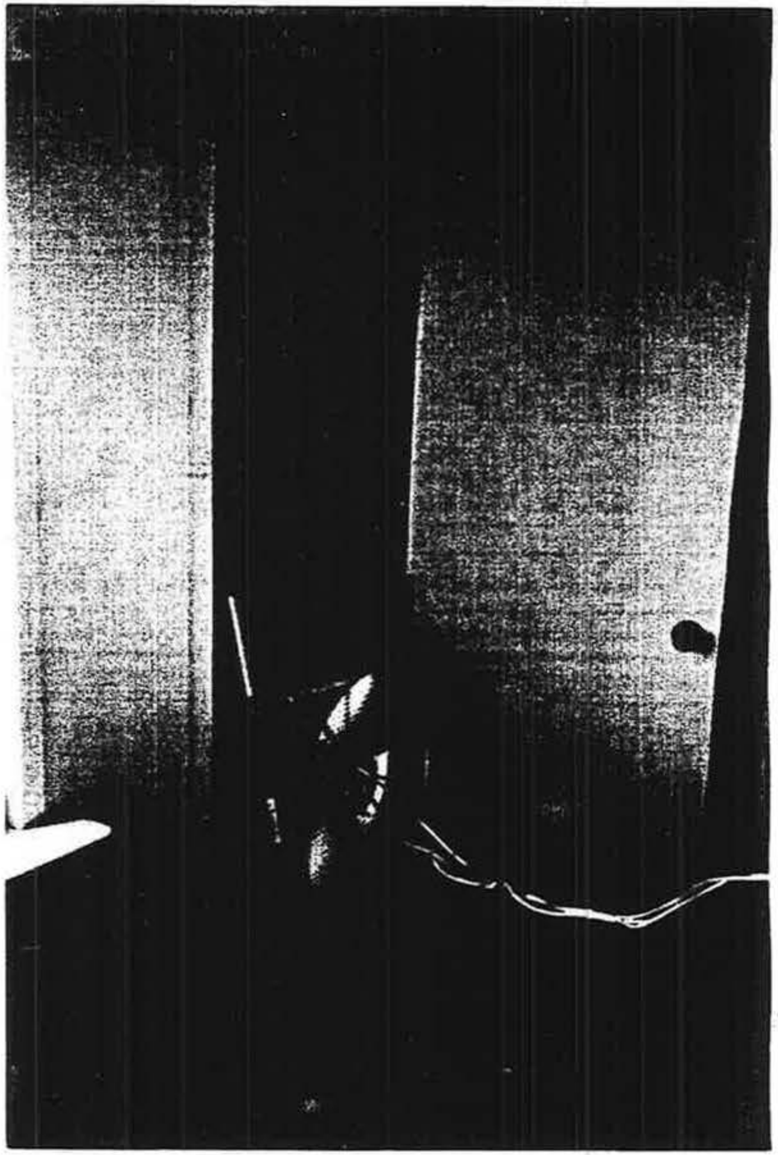


Elevator shaft pulley holes are often the largest leakage paths from the elevator shafts into the penthouse.

Smoke pencils can be used to detect both infiltration and exfiltration paths, with or without fan depressurization during the winter.



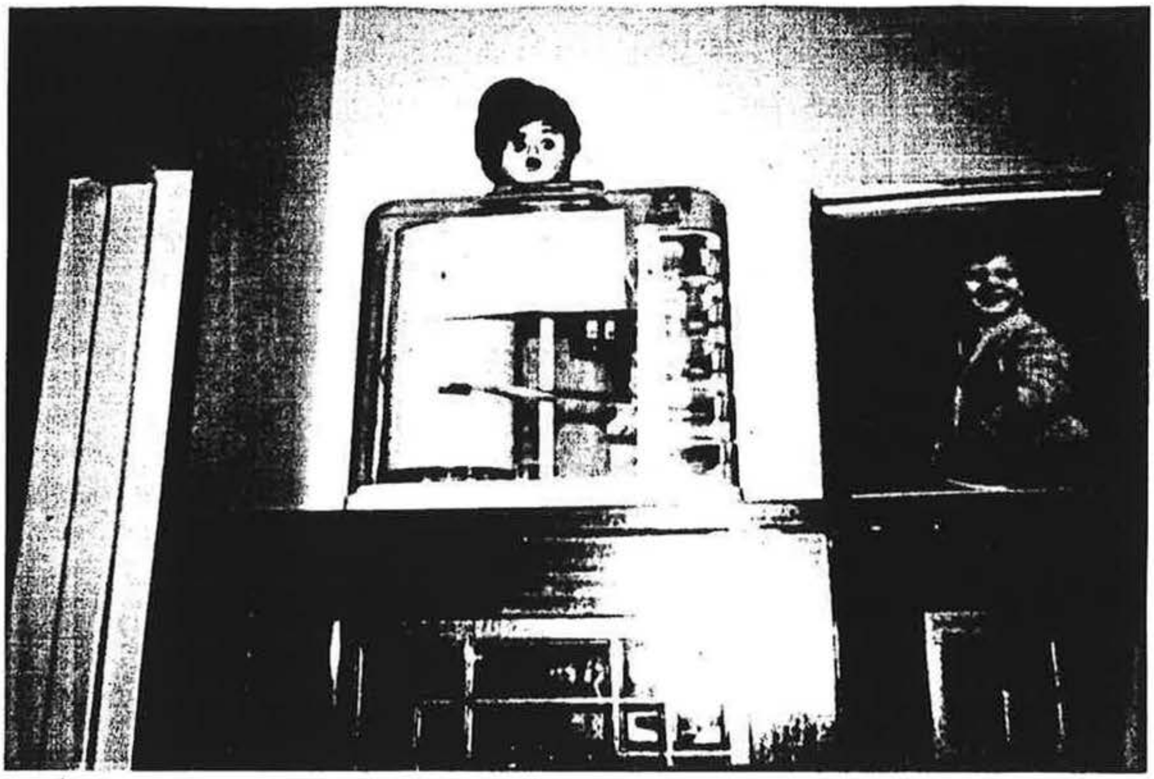
Individual window tests are done to assess the air leakage characteristics of that component of the building envelope.



Fan depressurization of individual apartments can help to define typical leakage paths in the apartments.

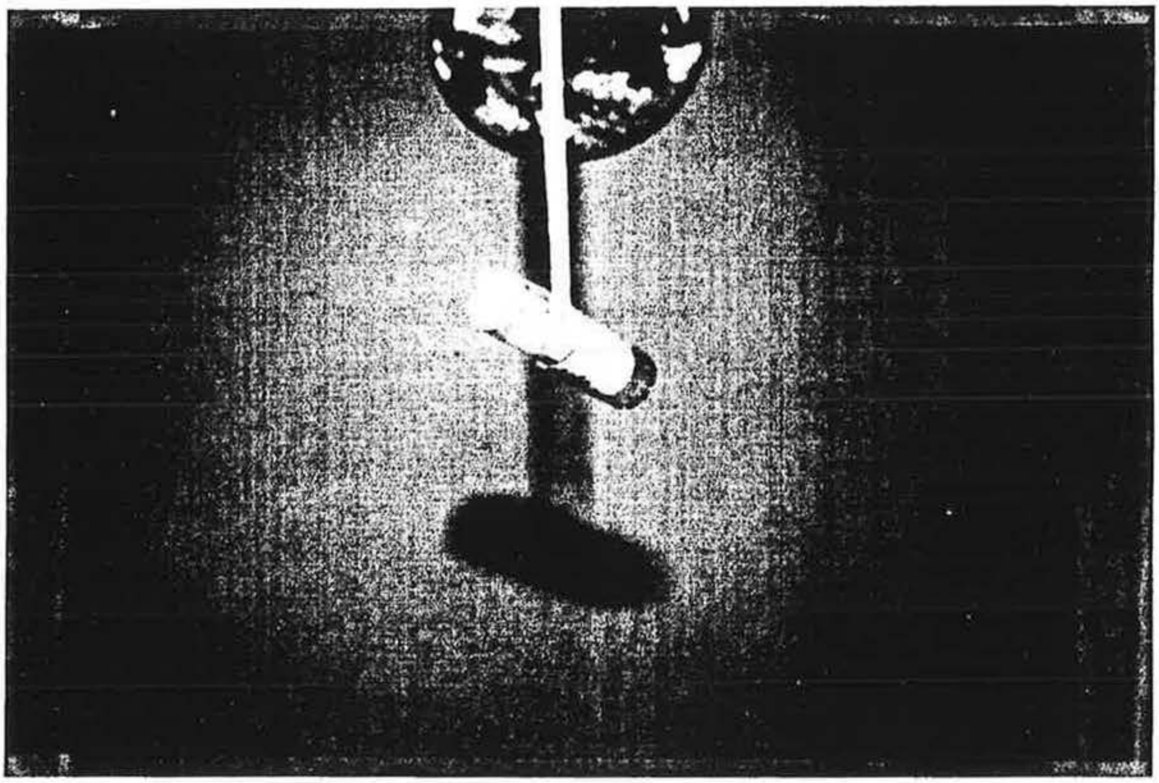

Air sealing work included window trim caulking.

Window sashes were removed, the weatherstripping was replaced then the sashes were reinstalled.

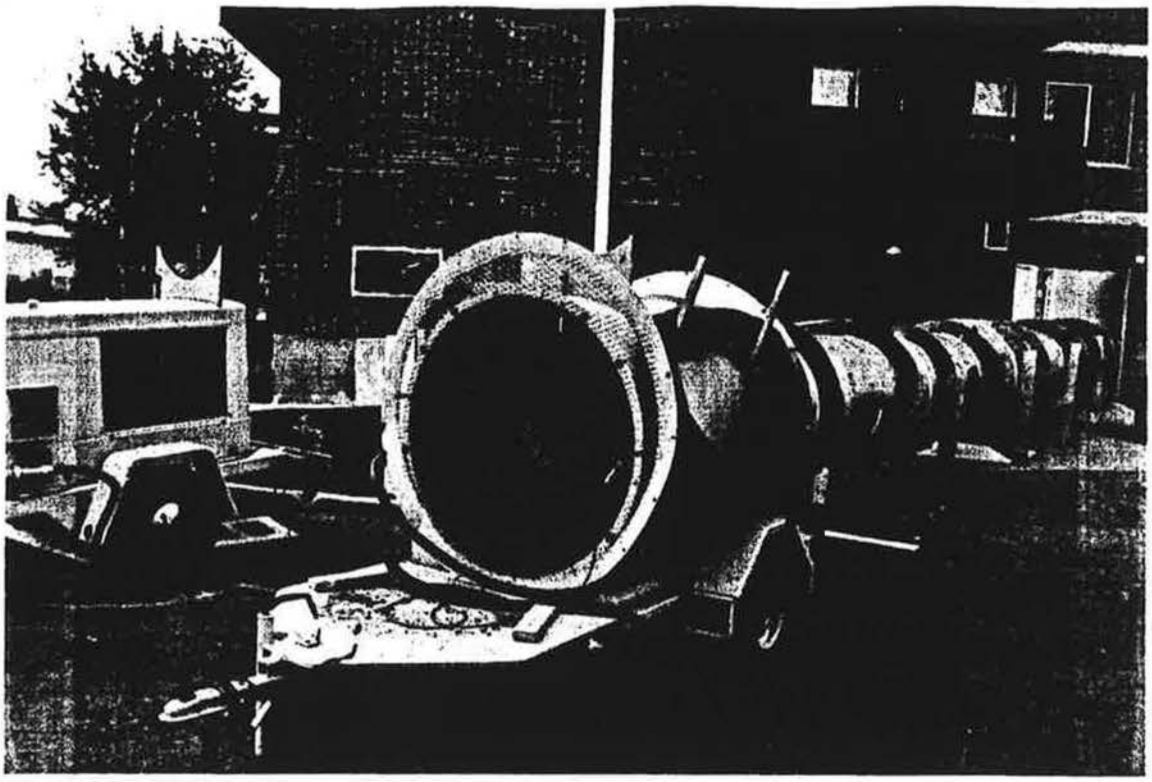


Air quality measurements were done before and after the air sealing.
Relative humidity and temperature in selected apartments were measured.

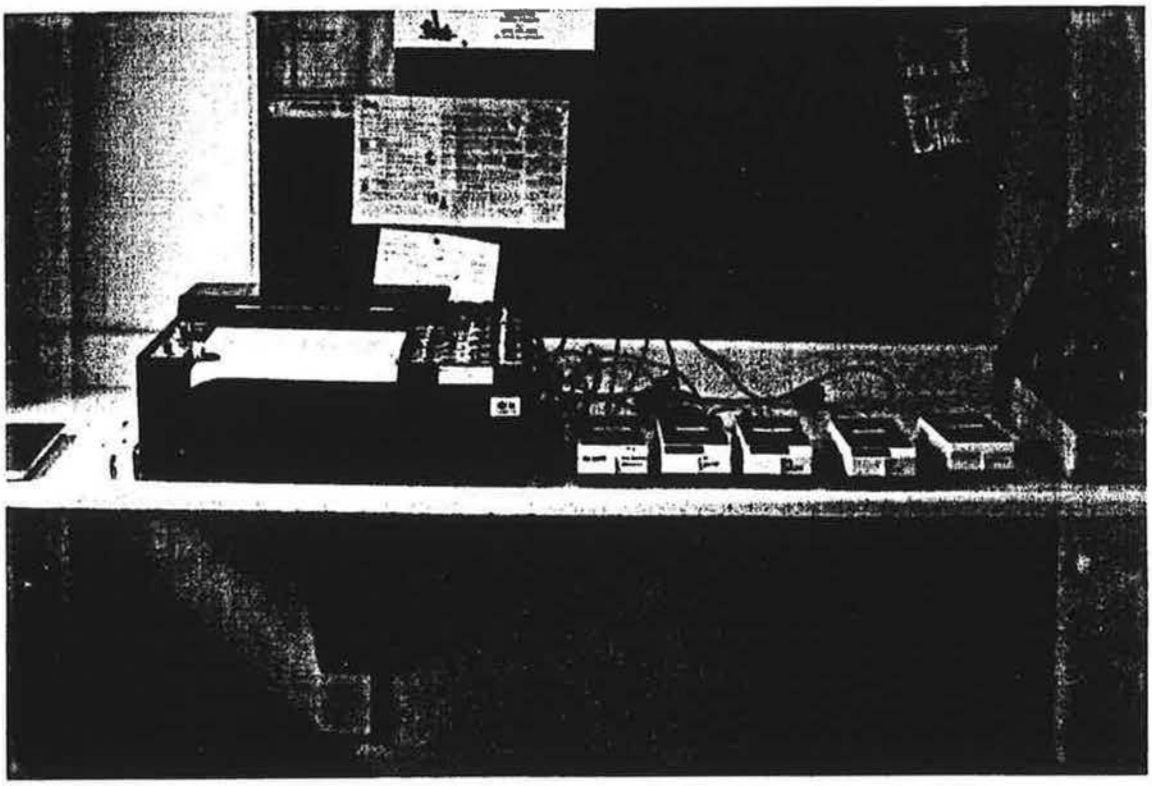
Carbon dioxide and Carbon monoxide were measured using Gastec tubes and hand held pumps.



AQR dosimeters were used to measure formaldehyde, before and after air sealing, as an additional indicator of indoor air quality and air change.



A whole building airtightness test was performed on the Ottawa building, before and after the air sealing, using the axial vane fan (NRC), to verify the air leakage assessment procedure. The fan is shown above and the recording equipment below.



4. IMPLEMENTATION OF AIR SEALING MEASURES IN HIGH-RISE BUILDINGS

4.1 Field and Application Considerations

The theoretical developments showed that the air-leakage component contributes to peak heating demand by 12 to 25 W/m^2 of floor space in high-rise residential buildings located in Ontario. There is potential to reduce this component by 4 to 10 W/m^2 of floor space by controlling the air infiltration. Therefore, the air leakage control or weatherization offers a potentially remarkable DSM opportunity for Ontario Hydro. An assessment of how to achieve this theoretical potential into a *practical viability* is one of the most important aspects of this project. The air leakage control or weatherization program for high-rise buildings should consider the following:

- Set criteria for air leakage control of buildings,
- Identification and assessment of potential benefits to Hydro and to the building owner(s),
- Implementation of air leakage control work, and
- Assessment of multi-storey residential weatherization program with regard to Hydro's DSM objectives.

4.1.1 Criteria for air leakage control of high-rise buildings

The definition of a high-rise building, as used in this project, emerges from several publications and building industry practises. A building of 8 storeys or higher (approximately 20 m or higher) falls in the category of "high-rise" residential buildings and this definition should be used in the development of the weatherization program. The criteria for the application of an air leakage control strategy can be defined as follows:

- the building has eight or more storeys;
- the main space heating fuel is electric, and the peak total building electric load during winter months is more than 150 kW (assumed on the basis of at least a 10 kW reduction in peak demand for the building);
- there were no major recent renovations to the building envelope which have improved the airtightness of the building; and
- owners are willing to participate in the weatherization program.

The above preliminary criteria are the minimum requirements which should be met before considering the building for further assessment.

4.1.2 Identification and assessment of potential benefits

Once the building satisfies the minimum set requirements and is pre-screened, a detailed technical assessment should be conducted to identify the potential benefits in terms of peak demand reduction and energy savings using the air-sealing assessment procedure (described in the following sections). The air leakage assessment procedure will lead through not only peak demand and energy consumption aspects, but also through indoor air quality and thermal comfort aspects arising from air leakage control. Such an assessment or audit of the building will assist in developing a cost-effective work plan for the air leakage control. The following components should be identified:

- potential reduction in peak electrical power and energy consumption,
- determination of Hydro's cost incentive based on peak demand reduction,
- cost estimates of air leakage control with and without Hydro's incentives,
- cost-benefit assessment based on priorities for air leakage control, and
- a preliminary work plan or action plan for the implementation of air-sealing.

If the air-leakage assessment procedure does not show acceptable benefits to either Ontario Hydro or to the building owner(s), the building should not be considered for weatherization. Otherwise, the engineering assessment of the air leakage in the building will become the stepping stone for further work. The air sealing assessment procedure will also provide a preliminary work plan for air sealing work.

4.1.3 Implementation

Implementation of air sealing work involves several factors:

- Selection of an air leakage control contractor from Ontario Hydro's approved list
- Air-sealing of the building as per the approved work order developed using the air-sealing assessment procedure
- Quality control and field inspections

Air-sealing of the building envelope is a very specialized trade. The success of weatherization depends on the quality of air-sealing of the building. In these regards, Ontario Hydro may have to develop specific training programs for contractors so that the high work quality and uniformity can be maintained. A quality control inspection should be conducted by the air-sealing assessor to verify the air-sealing. Performance based contracting is another way to maintain high-standards of quality.

A recent report prepared by Con-Serve Group and CanAm Building Envelope Specialists Inc. for Ontario Hydro provides the details on a training program for air leakage contractors, installation guidelines and air-sealing materials and equipment [CANAM 1991].

4.1.4 Assessment of weatherization program with regard to DSM objectives

Initially, there should be strict assessment of each air-sealed high-rise building to establish the effectiveness in reducing the peak power demand. A detailed monitoring of power demand and energy consumption before and after air sealing may be necessary to obtain reliable data. A quick comparison between monthly peaks may be sufficient enough in some cases.

Once there is sufficient confidence in the implementation of air-sealing work, a random sample of 5 to 10% of buildings can be compared for the benefits of air-sealing. A periodic assessment of the weatherization program should be conducted to evaluate its results in achieving the DSM set goals.

4.2 Air Sealing Techniques

The following guidance of air-sealing the high-rise buildings has been gathered from various sources and the practical experience of air leakage control contractors. The guidance can be equally applicable to retrofit and new buildings.

4.2.1 Minimize Stack Effect

Stack effect is a function of the building height, wind velocity and direction, and the temperature difference between indoors and outdoors. The created draft is in turn affected by certain external conditions, primarily the size and location of openings and pressures exerted on the draft.

As seen before, for tall buildings stack effect can be a predominant driving force for air leakage and hence account for a very substantial portion of the total heat loss. Since it is present continuously, the energy required to balance stack effect will be a higher portion of the total heating energy consumption. Thus it is very important to limit the stack effect in tall buildings.

With regard to various leakages the following suggestions are offered:

1) Cracks around doors to lobbies, elevators, stairwells and fire towers should be sealed as much as possible by some means of weatherstripping or caulking.

2) Lobby entrances should be equipped with double doors or revolving doors.

3) Retail shops incorporated in residential buildings' ground floors should be studied for careful and proper control of openings between shops and an adjacent lobby which could be another path for air infiltration.

4) All openings for mechanical equipment such as outdoor exhaust and relief air louvres should be equipped with properly designed dampers having neoprene edges so that positive shut-down with minimum leakage can be achieved. Any other openings made to accommodate mechanical work, such as clearance around piping in walls and floors, should be effectively plugged to reduce air flow.

5) Care should be taken in the construction of core walls to eliminate the possibility of excessive cracking and consequent air infiltration.

6) Careful selection of door self-closures for stairwells should be made to ensure that they can function and close against stack effect.

7) Mechanical ventilation equipment and heat recovery systems should be monitored and serviced regularly to ensure design specifications and proper operation are being maintained. Often, when this type of equipment is not maintained after a building's construction, proper operation deteriorates resulting in serious heating losses.

In regard to pressure influencing draft, the following points can be made:

1) A positive pressure developed within the building will effectively reduce the amount of infiltration. Consequently, the mechanical ventilation system should introduce a decidedly greater quantity of fresh air into the building in comparison to the amount of air exhausted. However, energy implications should be considered for such changes in retrofit situations.

2) Since stack pressures will be developed in elevator machine rooms through the shaft smoke holes, the design of their ventilating systems should take this into consideration. A fan supplying air to the machine room and connected to the outdoors should be capable of developing the required system pressure losses plus the stack pressure. An exhaust fan, on the other hand, should be selected on the basis of the stack pressure acting in concert with the fan's developed pressure. In many cases, an exhaust fan for upper floor ventilation is not necessary since the stack pressure could provide for the proper quantity of exhaust air through controlled openings to the outdoors.

   Many buildings have an elevator penthouse with a thermostatically controlled exhaust fan and louvres. During operation, these devices depressurize the building and increase infiltration problems at the ground level.

3) A possible solution is the installation of a static pressure control in the elevator machine room to modulate motorized dampers in louvred outdoor openings. This arrangement would utilize the stack effect as the pressure required for the proper exhaust of air. As the outdoor temperature increased and the static pressure fell off, the machine room temperature would tend to climb due to improper ventilation. A thermostat would automatically start the exhaust fan and possibly an air supply system. Another solution is to close outdoor dampers and mechanically cool the elevator machine rooms.

4) Although stack effect is the most important cause of air infiltration, it is important to note that wind pressure is an important factor on the overall building pressure. The overall infiltration rate is governed by the larger of the two motive forces, and the exterior wall pressure differences at any level caused by wind and stack action are additive.

5) If, by air pressurization, the "neutral zone" is lowered to ground level, air infiltration is eliminated but exfiltration is increased. The required rate of supply of outside air can be calculated. Reducing the infiltration rate by pressurizing incurs a high heating cost penalty. It is more economical to pressurize the ground floor only, provided the ground floor enclosure is reasonably air tight. Vestibule supply units can also play a part in reducing air inrush at the entrance door.

6) Studies have been concluded on high rise buildings at the National Research Council of Canada, with regard to using the central shaft with blowers to blow downward from the neutral level, in an attempt to reduce air pressure differences across exterior walls. The results show reductions in pressure differences across the exterior walls would depend on the recirculation rate and the internal resistance of a building. Inside pressures of a building with a low internal resistance will not be altered sufficiently to affect the pressure differences across the exterior walls.

It was also noted that if both infiltration and exfiltration were eliminated by this means, then the pressure differences caused by temperature differences (stack action) would be transferred from the exterior walls to the walls of vertical shafts which can give rise to difficulties in operating elevators and stair doors. It is probable that the operation of this type of system would be difficult. The preferred approach to reduce infiltration is by better outside wall construction so that walls are relatively air tight, rather than using ventilation fans for pressurizing buildings.

4.2.2 Minimize Air Infiltration in High-rise Buildings

1) An infrared scan (thermograph) permits the location of warm air losses when the outside temperature is low. Surface temperature indications using thermography (or surface temperature probes) not only reveal variations in insulation, but also highlight unusual leakage areas.

2) To control infiltration, a review of the following building characteristics is recommended:

   a. Air leakage through roof vents and sky lights;
   b. Air leakage up elevators and stairwells;
   c. Air leakage at revolving entrance doors or pressurized double door entrances;
   d. Air leakage through shipping and receiving rooms;
   e. Air leakage through open windows;
   f. Heat loss through ventilating systems.

3) Air infiltration alone cannot be relied upon to provide an adequate amount of outdoor air for the ventilation of buildings with curtain wall construction and fixed glazing. The heating load caused by ventilation air was found to be one of the major components of total heating load. Reducing air infiltration by mechanically pressurizing a building can represent a high heating cost penalty.

4) Roof and perimeter wall junctions in high-rise multi-residential buildings should be considered to reduce heat loss at a considerably small cost.

5) Control of entrance infiltration is an important way to reduce building energy consumption. Entrance traffic rate, height of building and temperature differences cannot be controlled. Reducing entrance infiltration can be accomplished by one or more of the following:

   a. Reducing the pressure differential across the entrance by sealing or tightening other parts of the building envelope;
   b. Reducing the pressure differential across the entrance by pressurizing the structure with outdoor ventilation;
   c. Sealing the entrance by using the proper type of entrance doors (revolving doors). There should be no infiltration across entrances no matter how high the building.

6) A critical location for leakage in buildings is associated with the junction of wall and roof and wall and ground floor. This may be further aggravated when dropped ceilings are provided for service spaces and the exterior wall above the ceiling is left unsealed or is inadequately treated with regard to air tightness.

7) Air leakage through exterior walls can also occur when the structural system or services penetrate the air barrier, or where joints between dissimilar materials or components occur. Masonry can not be installed tightly to structural steel columns and beams.

8) Air leakage should never be relied upon for ventilation or air supply and exhaust.

4.3 Implementation of Air Sealing Program

The implementation of a province-wide air leakage control program will be required to meet the DSM objectives. In each electrically heated high-rise residential building, the air-sealing would involve the following components:

1. Pre-screening of the building for air leakage control;
2. Field assessment of air leakage and potential control strategies, cost benefits, and decision scenario;
3. Selection of an air leakage control contractor from Ontario Hydro's approved list;
4. Air-sealing of as per the approved work order developed using the air-sealing assessment procedure; and
5. Quality control and evaluation based on DSM objectives.

Appendix A provides more information on above components.

4.4 Related Issues

This project set out with a principal objective of developing the required assessment procedure for evaluating the potential effects and benefits of air sealing of high-rise buildings. Feasibilities of air-sealing work was demonstrated and validated with the measured reductions in peak power demand. There are still certain components which should be looked into for a successful implementation of the high-rise residential weatherization program.

- The computer implementation of the assessment procedure would assist in further simplification of the procedure by making it more user-friendly. The assessment procedure was developed in the modular fashion to ease the computer implementation.

- A detailed quality control program should be established to verify and raise a higher degree of confidence in the assessment procedure. This would involve "whole" building airtightness tests and energy consumption monitoring of at least 5 to 10% of the proposed buildings.

- A training program should be established for the air-sealing assessors and the air leakage control contractors to effectively implement the program.

The implementation of a high-rise leakage control (weatherization) program must be done with full consideration of the issues related to performance contracting, training of air-sealing assessors and air leakage control contractors, and quality control. Effective implementation of such a program would benefit Ontario Hydro and the building owners.

5. CONCLUSIONS AND RECOMMENDATIONS

A simplified procedure has been developed for assessing air leakage and its control potential for electrically heated high-rise residential buildings of eight storeys and higher (20 m or higher). This procedure has three components: field assessment of air leakage paths in the building; calculation of air leakage rate at the winter design conditions; and cost-benefit assessment and development of work plan for air-sealing.

Two high-rise residential buildings were selected for the demonstration of air-sealing work and the validation of the assessment procedure. The monitored results showed that the peak demand reduction in the Donald Street building in Ottawa (floor space of 14,290 m^2), was 85 kW at the winter design conditions (11% of the peak electric demand). The saving in energy consumption during the heating season was 165 MWh or roughly 12% of the space heating energy use. At the Bridleview building in Toronto (floor space of 9,825 m^2 - building make-up air heated with natural gas), the electric demand reduction was 42 kW (8.5% of the peak electric demand). The savings in electric energy consumption during the heating season was 63.3 MWh or roughly 6.5% of electric space heating energy use. The assessment method predicted the potential savings in energy and power consumption within 5 to 10%.

Based on the successful demonstration of air-sealing work and the assessment procedure, it can be concluded that the air leakage control or weatherization offers a potential to reduce the peak electric demand by 4 to 10 W/m^2 of floor space depending on the location and building characteristics. A simplified analysis of Ontario's high-rise residential building stock suggests an air leakage control potential of roughly 6 W/m^2 of floor space.

Cost-benefit assessment showed that the average cost of air-sealing varied from $645 to $880 per kW of demand reduction for the two test buildings. The sealing of elevator shafts (top, bottom and external walls), garbage chutes (top and bottom) and stairways was the most cost effective air-sealing practise in both buildings. The second most cost effective methods were the sealing of the exterior envelope, windows and doors, based on cost and potential peak demand savings.

Indoor air quality tests showed that the air sealing of the building had no negative impact on the general conditions of comfort and air quality in both buildings. In both these buildings, it was also observed that the air sealing had reduced the movement of stale odours. In fact, the sealing allowed for more consistent adjustment of air supply to the apartments.

It is recommended that the assessment procedure be used for the estimation of the air leakage rate in high-rise buildings. A user-friendly computer application of the assessment procedure would certainly assist in ease of implementation. A detailed quality control program should be established to verify and raise a higher degree of confidence in the assessment procedure.

The implementation of a high-rise leakage control (weatherization) program should consider the issues related to performance contracting, training of air-sealing assessors and air leakage control contractors, and quality control. Successful implementation of such a program would benefit both Ontario Hydro and the building owners.

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APPENDIX A: ASSESSMENT PROCEDURE

HIGH-RISE RESIDENTIAL WEATHERIZATION: PROCEDURE FOR ASSESSING AIR LEAKAGE AND POTENTIAL CONTROL IN ELECTRICALLY HEATED RESIDENTIAL BUILDINGS OF EIGHT STOREYS AND HIGHER

MULTI-STOREY RESIDENTIAL BUILDINGS WEATHERIZATION PROJECT

HIGH-RISE RESIDENTIAL WEATHERIZATION: PROCEDURE FOR ASSESSING AIR LEAKAGE AND POTENTIAL CONTROL IN ELECTRICALLY HEATED RESIDENTIAL BUILDINGS OF EIGHT STOREYS AND HIGHER

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May 1991

HIGH-RISE RESIDENTIAL BUILDINGS WEATHERIZATION PROJECT

PROCEDURE FOR ASSESSING AIR LEAKAGE AND POTENTIAL CONTROL IN HIGH-RISE RESIDENTIAL BUILDINGS (Electrically Heated Eight Storeys and Higher)

The purpose of this procedure is:

- to characterize the building and assess its air-sealing potential and to reduce energy usage; and

- to estimate the relative importance of various air leakages and to establish the priorities for air-sealing work.

The procedure has been assembled in the following parts:

- Building Audit and Field Inspection
- Estimation of the Uncontrolled Air Leakage Component
- Determination of Air Sealing Priorities
- Development of Work Plan for Air Sealing of the Building.

The building should be described by completing the first part - Building Audit and Field Inspection - during the site visit. The attached **Guide** provides the description of various field inspection procedures and suggests *"what to look for"* the building to assess air leakages. The Guide also suggests appropriate air leakage characteristics of various building envelope components.

The second part assists in the estimation of the uncontrolled air leakage component as a whole. With the data gathered from the field visit, the calculation of air leakage is determined using the step-by-step method. The electric savings potential in reducing the leakage is then calculated. The **Guide** explains each step in detail with an example.

The third and fourth parts deal with determining the air sealing priorities and the development of a work plan for air-sealing the building.

Please read the attached **Guide** to familiarize with the air-sealing assessment procedure.

HIGH-RISE WEATHERIZATION PROJECT

PROCEDURE FOR ASSESSING AIR LEAKAGE AND POTENTIAL CONTROL IN HIGH-RISE RESIDENTIAL BUILDINGS

Part A: Building Audit and Field Inspection

Inspection Date: **Time:**

Identification Number:

1. Building Identification

1.1 Job Name and Address

Job Name: ______________________________
____

Address: ______________________________
____

Contact: ____________________ **Phone:** ( ) -
FAX: ( ) -

1.2 Customer Name and Address

Customer Name: ______________________________
____

Address: ______________________________
____

Contact: ____________________ **Phone:** ( ) -
FAX: ( ) -

Other Contacts: ____________________ **Phone:** ( ) -

____________________ **Phone:** ( ) -

2. Site Plan

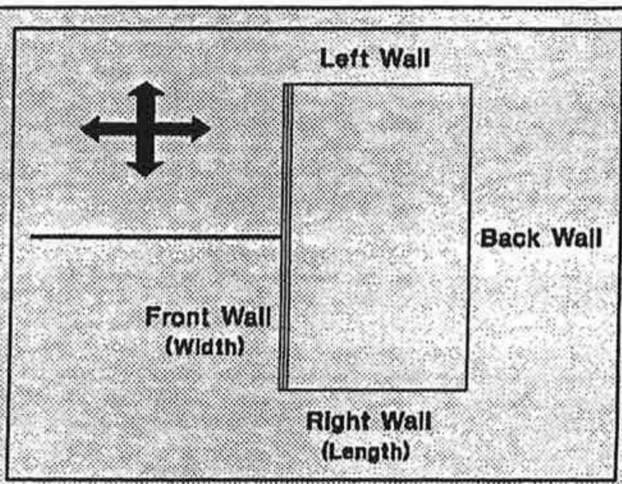
Please sketch of plan view and elevation. Indicate the overall dimensions, north arrow directions and ground floor, and typical floor and roof layout. (From architectural drawings or site-plans if available.)

Assign Orientations:

Front Wall: __________
Right Wall: __________
Back Wall: __________
Left Wall: __________

Dimensions:

Front Wall: __________ m
Right Wall: __________ m
Back Wall: __________ m
Left Wall: __________ m



Building Dimensions and Directions

Site Plan (continued)

Building Dimensions and Areas (from drawings and plans if available)

Building Floor Area and Volume: Determine the total enclosed heated and unheated floor area of the building.

Exposed Building Envelope Area: Determine the total building envelope area using the exterior dimensions, inclusive of walls, roof, windows (including frames), doors and exposed floors.

3. Building Description and Occupancy

Year of Construction: [   ] **Number of Stories:** [   ]

Type of Construction: ______________________________

Occupancy: [   ] (total)

Number of Suites: 1 BR: ___ 2 BR: ___ 3 BR: ___ Other: ___

Wind Shielding: [ ] (Consider the surroundings <u>within</u> a radius of the height of the building times 4 or so.)

1. Building in an open and flat terrain (very exposed - e.g., airport)
2. Suburban (exposed - cluster of low-rise buildings only)
3. Urban (mostly shielded - by other high-rise buildings)

Building Shape: [ ]
(plan view)

1. Rectangular or square
2. L shaped
3. C shaped
4. E shaped
5. T shaped
6. Other

Compass Orientation of Front Wall (degrees from North): [   ] **or one of the below:** [   ]

1. North 2. NE 3. NW 4. South 5. SE 6. SW 7. East 8. West

Building Dimensions:
(from plans/sketch)

Width (Front Wall): __________ m
Length: __________ m
Height: __________ m

Total Floor Area:

Heated: m^2
Unheated: ____________ m^2
Total: m^2

Building Volume:

Heated: m^3
Unheated: ____________ m^3
Total: m^3

Building Exterior Envelope Area:
(above grade)

Walls: m^2
Windows: m^2
Roof: m^2
Doors: m^2
Other: ____________ m^2
Total: m^2

4. Energy Use

4.1 Fuels by End Use

Space Heating: ☐
1. Electric Baseboard
2. Central heating by electric
3. Natural Gas
4. Oil or other

Space Cooling: ☐
1. Window air-conditioners (how many? ______)
2. Central cooling using electric chillers
3. Other
4. None

Make-up Air Heating: ☐
(Supplied to corridors)
1. Electric Baseboard
2. Central heating by electric
3. Natural Gas
4. Oil or other

Make-up Air Cooling: ☐
(Supplied to corridors)
1. Central cooling using electric chillers
2. Other
3. None

Hot Water: ☐
1. Electric
2. Natural Gas
3. Oil
4. Other

4.2 Electric Rates

Consult with local Hydro representative or check the current electric bill to indicate applicable format and electric rates.

Type of Service: ☐ 1. Residential 2. General 3. Commercial 4. Time of Use & Large User 5. Other

			WINTER	SUMMER
Energy:	First	________ kWh at	______ cents/kWh	______ cents/kWh
	Next	________ kWh at	______ cents/kWh	______ cents/kWh
	Next	________ kWh at	______ cents/kWh	______ cents/kWh
	Balance	________ kWh at	______ cents/kWh	______ cents/kWh
Demand:	First	________ kW at	______ $/kW	______ $/kW
	Balance	________ kW at	______ $/kW	______ $/kW

Peak Demand Hours: From _____ o'clock to _______ o'clock (Winter)
From _____ o'clock to _______ o'clock (Summer)

Building Component	Front Wall ( )		Right Wall ( )		Back Wall ( )		Left Wall ( )	
	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class
Type 4: ________________ Description: Size: Quantity: ________ -Weatherstripping Perimeter per window: _________ m -Caulking perimeter: _____ m -Other	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____
Doors								
Type 1: ________________ Description: Size: Quantity: ________ -Weatherstripping Perimeter per door:_________ m -Caulking perimeter: _____ m -Other	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____
Type 2: ________________ Description: Size: Quantity: ________ -Weatherstripping Perimeter per door:_________ m -Caulking perimeter: _____ m -Other	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____
Type 3: ________________ Description: Size: Quantity: ________ -Weatherstripping Perimeter per door:_________ m -Caulking perimeter: _____ m -Other	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____	_____ _____ _____

Building Component	Front Wall ( )		Right Wall ( )		Back Wall ( )		Left Wall ( )	
	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class
Envelope Leakages								
Description:								
1. ______	___	___	___	___	___	___	___	___
2. ______	___	___	___	___	___	___	___	___
3. ______	___	___	___	___	___	___	___	___
4. ______	___	___	___	___	___	___	___	___
5. ______	___	___	___	___	___	___	___	___
6. ______	___	___	___	___	___	___	___	___
7. ______	___	___	___	___	___	___	___	___
8. ______	___	___	___	___	___	___	___	___
Louvres and Exhaust Hatches								
-Size of exhaust louvre:	___	___	___	___	___	___	___	___
-Fresh air fan grilles:	___	___	___	___	___	___	___	___
-Laundry room exhaust:	___	___	___	___	___	___	___	___
-Other	___	___	___	___	___	___	___	___
Miscellaneous								
-Water hose bibs	___	___	___	___	___	___	___	___
-Electric fixtures	___	___	___	___	___	___	___	___
-Fire hoses	___	___	___	___	___	___	___	___
-Transformer entry door	___	___	___	___	___	___	___	___
-Other	___	___	___	___	___	___	___	___
-	___	___	___	___	___	___	___	___
-	___	___	___	___	___	___	___	___
Other Notes								
1. ______	___	___	___	___	___	___	___	___
2. ______	___	___	___	___	___	___	___	___
3. ______	___	___	___	___	___	___	___	___
4. ______	___	___	___	___	___	___	___	___
5. ______	___	___	___	___	___	___	___	___

6.2 Typical Floor (Between 2nd and Top Floor - Exterior Envelope)

Building Component	Front Wall ( )		Right Wall ( )		Back Wall ( )		Left Wall ( )	
	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class
Windows								
Type 1: ________________ Description: Quantity: _____ -Weatherstripping Perimeter per window: __________ m -Caulking perimeter: _____ m -Other								
Type 2: ________________ Description: Quantity: _____ -Weatherstripping Perimeter per window: __________ m -Caulking perimeter: _____ m -Other								
Type 3: ________________ Description: Quantity: _____ -Weatherstripping Perimeter per window: __________ m -Caulking perimeter: _____ m -Other								
Doors								
Type 1: ________________ Description: Quantity: ________ -Weatherstripping Perimeter per door:_________ m -Caulking perimeter: _____ m -Other								

Building Component	Front Wall ( )		Right Wall ( )		Back Wall ( )		Left Wall ( )	
	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class
Type 2: ________ Description: Quantity: ____ -Weatherstripping Perimeter per door:_____ m -Caulking perimeter: ____ m -Other								
Envelope Leakages Description: **1.** ________ **2.** ________ **3.** ________ **4.** ________ **5.** ________ **6.** ________ **7.** ________ **8.** ________								
Louvres and Exhaust Hatches -Size of exhaust louvre: -Fresh air fan grilles: -Other								
Miscellaneous -Electric fixtures -Other -								
Other Notes **1.** ________ **2.** ________ **3.** ________								

6.3 Underground Parking and Basement Survey

Please refer to **Guide** for more information. Air leakage into a basement or underground parking may be controlled by sealing the perimeter envelope, above grade and below, or by sealing the separating elements that isolate the basement from the building above. It is always preferable to focus only on sealing the separating elements: the floor above, all penetrating shafts, stair doors, elevator vestibules etc. In such cases, only these separating elements need be assessed below.

	Description	Air-Sealing Method	Leakage Length (m)	Leakage Class
1.	**Basement Exterior Doors:**			
	- Weatherstripping perimeter: ________ m.	______	______	______
	- Caulking perimeter: ________ m.	______	______	______
	Basement Exterior Windows:			
	- Weatherstripping perimeter: ________ m.	______	______	______
	- Caulking perimeter: ________ m.	______	______	______
	Exterior Envelope Cracks above Grade			
	Description:			
	1. ________ m.	______	______	______
	2. ________ m.	______	______	______
	3. ________ m.	______	______	______
	SEPARATING ELEMENTS			
2.	**Electrical Room**			
	1. Cable penetrations to the building ________ m^2	______	______	______
	2. ________	______	______	______
	3. ________	______	______	______
3.	**Boiler Room**			
	1. ________	______	______	______
	2. ________	______	______	______
	3. ________	______	______	______
4.				
	1. Elevator vestibule ________	______	______	______
	2. Stairwell and door ________	______	______	______
	3. Other ________	______	______	______
	4. ________	______	______	______

6.4 Mechanical Room, Penthouse and Roof Inspection

Please refer to Guide for more information. Air escaping the building through the mechanical room/penthouse may be controlled at the separation between the building and the room, or by attempting to seal the exterior envelope of a room, fan louvres etc. The former is almost always the more cost-effective line of attack. In such case, the assessor may ignore the following points on the penthouse envelope and focus only on the building roof and stairs.

Description	Air-Sealing Method	Leakage Length (m)	Leakage Class
Exterior walls and roof joint:			
1. ______	______	______	______
2. ______	______	______	______
3. ______	______	______	______
Exhaust Fans and Penthouse Ventilation Louvres	______	______	______
Floor Penetrations (building roof/penthouse floor):			
1. Pipe penetration	______	______	______
2. Cable penetration	______	______	______
3. Ducts	______	______	______
Stairs Connected to Penthouse (or Mechanical Room)			
1. ______	______	______	______
2. ______	______	______	______
Access Hatches at the Roof	______	______	______
Elevator Shafts			
1. Opening at the Cable Drive - 1 ______ m^2	______	______	______
2. Opening at the Cable Drive - 2 ______ m^2	______	______	______
3. ______ ______ m^2	______	______	______
Smoke Shafts			
1. Opening area at the top ______ m^2	______	______	______
2. ______ ______ m^2	______	______	______
Garbage Chute Hatches at the Roof			
1. Opening area at the top ______ m^2	______	______	______
2. ______ ______ m^2	______	______	______
Other			
1. ______	______	______	______

7. Interior Survey

Air leakage paths through the building envelope should also be assessed from the inside: Entry and overhead doors, main entrance overhangs, laundry room exhaust vents, garbage room chute, smoke shafts, pipe penetrations, fire doors, perimeter baseboard heaters, elevator shafts and garbage room.

7.1 Ground Floor, Hallway, Stairwell, Elevator Shafts and Service Shafts: Leaks to Outdoors

	Description	Air-Sealing Method	Leakage Length (m)	Leakage Class
1.	**Ground Floor**			
	- Main entrance projections	______	______	______
	- Other	______	______	______
	Envelope Leaks			
	1. ____________	______	______	______
	2. ____________	______	______	______
	3. ____________	______	______	______
	Service Rooms			
	1. ____________	______	______	______
	2. ____________	______	______	______
	3. ____________	______	______	______
	Halls			
	1. ____________	______	______	______
	2. ____________	______	______	______
	3. ____________	______	______	______
	Other			
	1. ____________	______	______	______
	2. ____________	______	______	______
	3. ____________	______	______	______
		______	______	______

(Interior Survey: Ground Floor and Shafts - Continued)

2. **Elevator Shafts:**

Leaks to outdoor: ____________ m^2

Other leaks: ____________ m^2

____________ m^2

Garbage Chutes:

Leaks to outdoor: ____________ m^2

Other leaks: ____________ m^2

____________ m^2

Stairwells:

Exposed opening: ____________ m^2

____________ m^2

Envelope leaks:

1. ____________________ ______ m ______ Class ______ width ______ m^2
2. ____________________ ______ m ______ Class ______ width ______ m^2
3. ____________________ ______ m ______ Class ______ width ______ m^2
4. ____________________ ______ m ______ Class ______ width ______ m^2

Fire Shafts (or Smoke Shafts):

Leaks to outdoor: ____________ m^2

Other leaks: ____________ m^2

____________ m^2

7.2 One Bedroom Suite Inspection (Leaks to outdoor)

	Description	Air-Sealing Method	Leakage Length (m)	Leakage Class
1.	**Interior Inspection** Baseboard heater: _______ m^2 Leaks around pipes and cable penetrations: _______ m^2 Leakage around exhaust fan ducts through exterior envelope: _________ m^2 Envelope leaks which are not included elsewhere: 1. ________________ 2. ________________ 3. ________________ 4. ________________	 ______ ______ ______ ______ ______	 ______ ______ ______ ______ ______	 ______ ______ ______ ______ ______
2.	**Depressurization test:** If the unit is depressurized using the blower door fan, note the various air leakage paths using smoke pencils or tracers. The air leakage from exterior envelope, party walls, exhaust fan, and pipe penetrations should be noted as follows: 1. Baseboard heater on exterior wall: Is the leak from baseboard heater an outdoor air leak or coming from party walls? If the air leak is from the party wall then the baseboard leak may not be a through envelope leak. 2. Floor and exterior wall joints 3. Ceiling and exterior wall joints 4. Balcony 5. Window / wall joint 6. Door and wall joint 7. Other observations			

7.3 Two Bedroom Suite Inspection (Leaks to outdoor)

	Description	Air-Sealing Method	Leakage Length (m)	Leakage Class
1.	**Interior Inspection** Baseboard heater: _______ m^2 Leaks around pipes and cable penetrations: _______ m^2 Leakage around exhaust fan ducts through exterior envelope: _________ m^2 Envelope leaks which are not included elsewhere: 1. ____________ 2. ____________ 3. ____________ 4. ____________	 ______ ______ ______ ______ ______	 ______ ______ ______ ______ ______	 ______ ______ ______ ______ ______
2.	**Depressurization test:** If the unit is depressurized using the blower door fan, note the various air leakage paths using smoke pencils or tracers. The air leakage from exterior envelope, party walls, exhaust fan, and pipe penetrations should be noted as follows: 1. Baseboard heater on exterior wall: Is the leak from baseboard heater an outdoor air leak or coming from party walls? If the air leak is from the party wall then the baseboard leak may not be a through envelope leak. 2. Floor and exterior wall joints 3. Ceiling and exterior wall joints 4. Balcony 5. Window / wall joint 6. Door and wall joint 7. Other observations			

7.4 Three Bedroom Suite Inspection (Leaks to outdoor)

	Description	Air-Sealing Method	Leakage Length (m)	Leakage Class
1.	**Interior Inspection** Baseboard heater: _______ m^2 Leaks around pipes and cable penetrations: _______ m^2 Leakage around exhaust fan ducts through exterior envelope: _________ m^2 Envelope leaks which are not included elsewhere: 1. ____________ 2. ____________ 3. ____________ 4. ____________	 ______ ______ ______ ______ ______	 ______ ______ ______ ______ ______	 ______ ______ ______ ______ ______
2.	**Depressurization test:** If the unit is depressurized using the blower door fan, note the various air leakage paths using smoke pencils or tracers. The air leakage from exterior envelope, party walls, exhaust fan, and pipe penetrations should be noted as follows: 1. Baseboard heater on exterior wall: Is the leak from baseboard heater an outdoor air leak or coming from party walls? If the air leak is from the party wall then the baseboard leak may not be a through envelope leak. 2. Floor and exterior wall joints 3. Ceiling and exterior wall joints 4. Balcony 5. Window / wall joint 6. Door and wall joint 7. Other observations			

8. Miscellaneous Data

Description		Air-Sealing Method	Leakage Length (m)	Leakage Class
1.				
2.				
3.				
4.				

Notes

Notes

PROCEDURE FOR ASSESSING AIR LEAKAGE AND POTENTIAL CONTROL IN HIGH-RISE RESIDENTIAL BUILDINGS (Electrically Heated Eight Storeys and Higher)

Part B: Estimation of Uncontrolled Air Leakage

The estimation procedure includes the following sections:

- Determination of air leakage area
- Determination of pressures due to stack, wind and mechanical ventilation
- Calculation of air leakage flow rates at different heights
- Estimation of net air leakage component
- Estimation of savings in peak electric heating demand and energy consumption due to air-sealing
- Determination of air-sealing priorities

1. Weather Data

The peak air infiltration occurs during the peak winter design conditions. The winter design conditions can be obtained from Table ?? of Guide or National Building Code. (For example, the winter design temperature for Toronto is -18 C, mean wind speed for air leakage calculations is 11.5 m/s and the heating degree days are 3646 C-days.) The field inspection visit provides information on the surrounding wind shielding conditions.

Location	
Winter Design Temperature 2.5%, °C	
Mean Wind Speed, m/s	
Wind Shielding and Terrain Type	
Heating Degree Days (below 18 °C)	

2. Calculation of Air Leakage Area

Determine the air leakage area using the field inspection data.

Storey	Component	Front Wall			Right Wall			Back Wall			Left Wall			Total Leakage
		Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Area, m^2 5+8+ 11+14
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	
Ground -exterior envelope	**Windows**													
	Type 1													
	Type 2													
	Type 3													
	Type 4													
	Total													
	Doors													
	Type 1													
	Type 2													
	Type 3													
	Total													
	Envelope Leakages													
	1.													
	2.													
	3.													
	4.													
	5.													
	Total													

Storey	Component	Front Wall			Right Wall			Back Wall			Left Wall			Total Leakage Area, m² 5+8+11+14
		Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	
Ground	Miscellaneous													
-exterior	Exhaust louvres													
envelope	Fresh air fan grilles													
	Laundry exhaust													
	Water hose bibs													
	Electric fixtures													
	Fire hoses													
	Other 1.													
	2.													
	3.													
	Total													
	Total Leakage Area (m^2)													

Storey	Component	Front Wall			Right Wall			Back Wall			Left Wall			Total Leakage
		Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Area, m^2 5+8+ 11+14
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	
Typical floor between 2nd and top floor -exterior envelope	Windows													
	Type 1													
	Type 2													
	Type 3													
	Type 4													
	Total													
	Doors													
	Type 1													
	Type 2													
	Type 3													
	Total													
	Envelope Leakages													
	1.													
	2.													
	3.													
	4.													
	5.													
	Total													

Storey	Component	Front Wall			Right Wall			Back Wall			Left Wall			Total Leakage Area, m² 5+8+11+14
		Leakage Length & Class	Assign Leakage Value	Leakage Area (m²)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m²)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m²)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m²)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	
Typical	Miscellaneous													
floor	Exhaust louvres													
between	Fresh air fan grilles													
2nd and	Laundry exhaust													
top	Water hose bibs													
floor	Electric lamps													
-exterior	Fire hoses													
envelope	Other 1.													
	2.													
	3.													
	Total													
	Total Leakage Area (m²)													

Shafts Leakage Area

Leaks connecting to outdoors or to top and bottom zones only.

Storey	Elevator Shafts Leakage Area, m^2			Stairwells Leakage Area, m^2		Service Shafts Leakage Area, m^2	Garbage Chute Leakage Area, m^2	Smoke Shafts Leakage Area, m^2	Total Leakage Area, m^2
	Elevator - 1	Elevator - 2	Elevator - 3	Stairwell - 1	Stairwell - 2				
Ground Floor and Basement									
2nd to Top Floor*									
Roof and Penthouse									
Total Leakage Area, m^2									

* Only where shafts form part of exterior envelope.

3. Total Leakage Area Summation

Storey	Windows (m^2)	External Doors (m^2)	Building Envelope (m^2)	Elevator & Service Shafts (m^2)	Miscellaneous (m^2)	Total Leakage Area (m^2)	Comments
Ground and Basement							
2nd to Top							
Roof and Penthouse							
Total Leakage Area							
Percentage of Leakage Area							

4. Calculation of Air Leakage Rates

4.1 Calculation of Stack Pressure, Ps

Stack pressure, Ps, can be obtained using the following equation:

$$P_s = \rho g(h1 - h2)[T_i - T_o]/T_o * TDC$$

where, Ps = pressure difference due to stack effect, Pa
rho = air density, kg/m^3 (use 1.18)
T_i = indoor temperature, K (use 293 K = 273 + 20 C)
T_o = outdoor temperature, K (winter design condition)
h2 = building height at which stack pressure is being determined, m
h1 = building height at which neutral pressure plane occurs (assume mid-height of building), m
TDC = Thermal Draft Coefficient (refer Table ?? of Guide)

The Table ?? provides value of stack pressures for four residential apartment buildings. These values can be used for first trial calculations.

4.2 Calculation of Wind Pressure, Pw

The wind pressure is given as,

$$P_w=(\rho C_p V_H^2)/2$$

where, Pw = average surface pressure due to wind, Pa
C_p = surface pressure coefficient, varies from 0.25 to 0.35 (refer Table ??)
V_H = wind speed, m/s

The wind speed, V_H, can be determined using the following equations:

$$V_H=A_o*V_{met}*(H/10)^a$$

where, H = height at which wind pressure is to be determined, m
V_{met} = mean wind speed obtained from metrological data, m/s
A_o, a = coefficients dependent on terrain and wind shielding (refer Table ?? of Guide)

Calculations:

1. Determine the following to calculate stack pressure distribution:

S1 = $[T_i - T_o]/T_o$ for example, for an indoor temperature of 20 C and outdoor temperature of -18 C, value of S1 is [(273+20)-(273+(-18))]/(273+(-18)) = 0.149

S1 =

S2 = density x gravitational constant = 1.18 * 9.81 = 11.58

S2 =

SC = S1 * S2 * TDC for example, 0.149 * 11.58 * 0.8

SC =

h1 = mid height of the building, m e.g. for a 80 m tall building, h1 = 40 m

2. Determine the following to calculate wind pressure distribution:

W1 = A_o * V_{met} for example, for a Toronto building in suburban terrain (A_o = 0.60 and V_{met} = 11.5 m/s), W1 = 6.9

W1 =

W2 = density * pressure coefficient / 2 = 1.18 * 0.25 / 2 = 0.148

W2 =

4.3 Calculation of Air Leakage Rate

The air flow rate through a leakage area A is defined as,

$$Q=C_d*A*\sqrt{2\Delta P/\rho}$$

where, Q = Air flow rate, m^3/s
C_d = discharge coefficient for the leakage path, varies from 0.65 to 0.85 (use 0.7)
A = Leakage area, m^2
rho = density, kg/m^3 (use 1.18)
ΔP = pressure difference across building envelope, Pa

4.4 Steps

The following forms are used to determine the air leakage rate at each floor. Steps are as follows:

- **Step 1.** Enter the height of each floor measured from the ground.
- **Step 2.** Enter the air leakage area from the previous sections.
- **Step 3.** Calculate the wind pressure *Pw* at each floor level using the equations as described above. The average wind pressure acting on the building envelope will induce air leakage in the building.
- **Step 4.** Determine the air-flow due to wind *Qw* using the wind pressure *Pw*.
- **Step 5.** First assume that the neutral pressure plane occurs at the mid height of the building. The value of *h1* will be (*height of the building / 2*).
- **Step 6.** Determine the stack pressure *Ps* using the equations as described above. The positive value of stack pressure indicate air infiltration into the building and negative values indicate exfiltration from the building.
- **Step 7.** Determine the air-flow due to stack *Qs* using the absolute value of stack pressure *Ps*. Assign the algebraic sign to this air-flow as that of *Ps*.
- **Step 8.** Determine the total air-flow *Q* for the floor, using the quadrature equation as defined above. Assign the algebraic sign to this air-flow as that of air-flow due to stack *Qs*.
- **Step 9.** Add the air infiltration flows *Qi* (positive values of *Q*) and air exfiltration flows *Qo* (negative values of *Q*). Compare *Qi* and *Qo*. If the difference is more than 5% (*(Qi-Qo)/Qi*), repeat the calculations from Step 5 by shifting the height of neutral pressure plane. If *Qi* is greater than *Qo*, then assume the neutral pressure plane one floor below than before. If *Qi* is smaller than *Qo*, then assume the neutral pressure plane one floor above than before. Repeat these calculations.
- **Step 10.** The net infiltration or exfiltration flow (*Qi* or *Qo*) is the uncontrolled air leakage rate.

(Please refer to illustrated example in the Guide)

Calculation of Air Leakage Rate

Instructions:	1. Height of building measured from above ground	2. Leakage area as calculated from Table ??.	3. Wind Pressure Calculations:	4. Stack Pressure Calculations	5. Air-flow Calculations
			- $W1 = A_o * V_{met}$ - $W2$ = air density * Cp / 2 $= 1.18*0.25/2 = 0.148$	- h1 is height of neutral pressure plane measured from the ground - $S1 = [T_i - T_o]/T_o$ - $S2 = 1.18 * 9.81 = 11.58$ - $SC = S1 * S2 * TDS$	- $Q1 = 0.7*(2/1.18)^{0.5} = 0.91$ - $Qs = A * Q1 * (\lvert Ps \rvert)^{0.5}$ - $Qw = A * Q1 * (Pw)^{0.5}$ - $Q = ((Qs)^2 + (Qw)^2)^{0.5}$ - Assign proper algebraic sign to *Qs* and *Q* depending on *Ps*.

Storey	Height h2	Leakage Area (m^2) *A*	Wind Pressure, *Pw*, (Pa)		Stack Pressure, *Ps*, (Pa)		Air-flow Calculations		
			$W3 = (W1*(h2/10)^a)$	$W2*(W3)^2$	Height Difference (h1-h2)	SC*(h2-h1)	Air-flow due to Stack (m^3/s) *Qs*	Air-flow due to Wind (m^3/s) *Qw*	Total air-flow (m^3/s) *Q*
Ground									
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									

Storey	Height h2	Leakage Area (m^2) *A*	Wind Pressure, *Pw*, (Pa)		Stack Pressure, *Ps*, (Pa)		Air-flow Calculations		
			$W3 = (W1*(h2/10)^a)$	$W2*(W3)^2$	Height Difference (h1-h2)	SC*(h2-h1)	Air-flow due to Stack (m^3/s) *Qs*	Air-flow due to Wind (m^3/s) *Qw*	Total air-flow (m^3/s) *Q*
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									
								Total Air Flow (m^3/s)	

4.5 Air Leakage Rate

The air infiltration rate in this building at peak design conditions is ____________ m^3/s or ______ L/s.

5. Calculations of Reductions in Peak Demand and Energy Consumption

The peak heating due to infiltration at the design weather conditions can be obtained by

$$HL_{infil} = Q_i \rho C_p \Delta T$$

where,

HL_{infil} = heat load due to air infiltration, kW
Q_i = air inflow rate, m^3/s
ρ = air density, kg/m^3 (about 1.18)
C_p = specific heat of air, kJ/(kg C) (about 1.0)

Using standard air ρ = 1.18 kg/m^3, and C_p = 1.0 kJ/(kg C), the above equation simplifies to:

$$q = 1.18 Q_i (T_i - T_o)$$

Infiltration air-flow Qi = _________ m^3/s Indoor and outdoor temperature difference is ______ °C.
Peak Heating Load, HL_{infil} = 1.18 * Qi * (Ti - To) Peak Heating Load = 1.18 *   * (-   ) kW kW

The above heat load is the total demand due to uncontrolled infiltration. Total air-sealing of the building would reduce the peak heat demand by this amount, but that is not practicable. Cost effective air-sealing will result in reducing a substantial portion. The reduction in heat load will be proportional.

For most high-rise residential the air-sealing effectiveness, $S_{effectiveness}$, may vary from 20% to a maximum of 40% depending on the extent of air sealing. The assessor's judgement will normally be in that range.

For high-rise buildings consider the following air-sealing effectiveness

Loose construction, $S_{effectiveness}$ = 0.40
Average construction, $S_{effectiveness}$ = 0.32
Tight construction, $S_{effectiveness}$ = 0.25

The reduction in peak heating demand due to air sealing will then be:

$$HL_{Infil(Reduction)} = S_{effectiveness} * HL_{Infil}$$

The $HL_{Infil(Reduction)}$ should be utilized in determining the incentive for air-sealing costs.

The energy reduction in energy consumption is given as following:

$$E = (HL_{Infil(Reduction)} * DD * C)/(\Delta T)$$

where, E = Annual reduction space heating energy, kWh
DD = Annual heating degree days, (C - days)
ΔT = Design temperature difference, C (Ti - To)
C = C-factor, Credit factor, hours/day

The value of degree days is obtained from the weather data. The C-factor allows credits for internal heat gains due to sun, lights, people, equipment, night setback and for the reduced mechanical ventilation. With these internal gains, only a fraction of the full load energy is actually required. This fraction is multiplied by 24 (hours/day) produces the "C" factor. For high-rise residential buildings, the C-factor varies from 14 to 18 hours/day. [Refer Guide for more information.]

Annual Heating Degree Days, *DD* = ______________ °C-days Design Temperature Difference, ΔT = *(Ti - To)* = (-) = C-factor = __________ hours/day
$E = (HL_{Infil(Reduction)} * DD * C)/(\Delta T)$

6. Ranking of Air-Sealing Priorities

6.1 Building Components

Based on component leakage area, the reductions in peak demand can be roughly ranked as follows:

Building Component	Percentage of Leakage Area (from page B-7)	Potential Demand Reduction, $HL_{Infil(Reduction)}$	Demand Reduction, kW	Ranking (ascending)
Exterior Windows				
Exterior Doors				
Building Envelope				
Elevators & Shafts				
Miscellaneous				

6.2 Leakage Area Distribution

Plot a distribution of air flows at each floor level on the attached graph. The leakage rates at the basement, ground, top floor and penthouse are generally higher than other floors. From the graph determine the predominant floors where air leakage rates are higher than other floors. If only these floors are air-sealed than it would result in reducing a substantial component of air leakage in the building. It has been established with several sensitivity analyses that, as a general rule, for a building the top 1/3rd and bottom 1/3rd height contributes more than 75 to 90% of total air leakage in the building (for example, for a 30 storey building, the bottom 10 floors and top 10 floors). From the graph, determine the following:

Below Neutral Pressure Plane (below the floor where air leakage rate is zero):

- Determine the total air infiltration rate (sum of all air leakage rates), *Qi*: ______ m^3/s
- Determine the air leakage rate for the bottom 1/3rd floor levels, *Qi(bottom 1/3)*: ______ m^3/s
- Ratio of *Qi(bottom 1/3) / Qi* = ____________________ = ________ **(B-6.2A)**

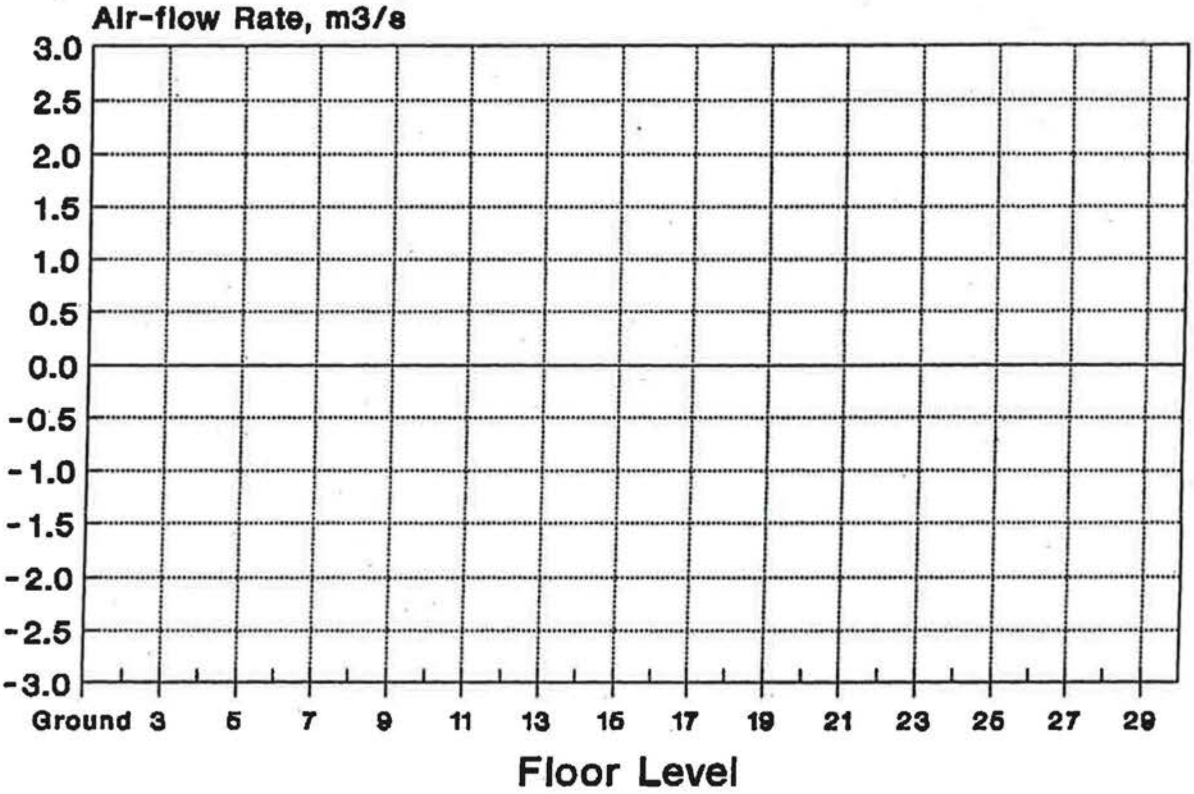
Above Neutral Pressure Plane (above the floor where air leakage rate is zero):

- Determine the total air exfiltration rate (sum of all air leakage rates), *Qo*: ________ m^3/s
- Determine the air leakage rate for the top 1/3rd floor levels, *Qo(top 1/3)*: ________ m^3/s
- Ratio of *Qo(top 1/3) / Qo* = ____________________ = ________ **(B-6.2B)**

- Ratio (B-6.2A) or (B-6.2B) is in the range of 0.7 or more: ☐ Yes ☐ No

If yes, the air-sealing of bottom 1/3rd and top 1/3rd height of building offers the potential peak demand reduction of $HL_{Infil(Reduction)}$ * *maximum of (B-6.2A or B-6.2B)* = __________ kW.

Profile of Air Leakage Rate
(Plot of *Q* and *Floor Level* - Page B-10)



7. Summary of Air-Sealing Assessment

ONTARIO HYDRO

HIGH-RISE RESIDENTIAL BUILDINGS WEATHERIZATION PROJECT

SUMMARY OF ASSESSMENT OF AIR LEAKAGE AND POTENTIAL BENEFITS

Job Name: ____________________ **Date:** ____________

Address: ____________________

____________________ **Telephone:** ____________

Building Type: ____________________ **Building Age:** ____________

Building Area: ____________________ m² **Heating Fuel:** ____________

An Ontario Hydro's weatherization assessor has been through your building to assess its suitability for air leakage control. The following table shows the air leakage control measures that are applicable to your building, based on assessor's findings. Note that the cost figures shown in the table are based on the assessor's preliminary estimates and that the final air-sealing implementation costs for the measures will be based on a detailed estimate done by an approved air-sealing contractor.

Air-Sealing Measure		Description	Estimated Potential Energy Savings			Estimated Implementation Costs		
			Demand (kW)	Energy (kWh)	Costs ($)	Owner's Contribution ($)	Ontario Hydro's Contribution ($)	Total ($)
1.	Windows							
2.	External Doors							
3.	Building Envelope							
4.	Elevator & Service Shafts							
5.	Miscellaneous							
		Total						

APPENDIX B: SAMPLE CALCULATIONS

HIGH-RISE WEATHERIZATION PROJECT

AIR SEALING ASSESSMENT PROCEDURE FOR HIGH-RISE RESIDENTIAL BUILDINGS

Part A: Building Audit and Field Inspection

Inspection Date: **Time:**

Identification Number:

1. Building Identification

1.1 Job Name and Address

Job Name: Ottawa-Carleton Regional Housing Authority

Address: 251 Donald Street
Ottawa, Ontario

Contact: Phil Renaud **Phone:** (613) 724-3327
FAX: (613) 728-3404

Building Suprintendant: Ed Treparier: 235 4305

1.2 Customer Name and Address

Customer Name: OCRHA

Address: 1545 Carling Avenue
Ottawa, Ontario K1Z 8R3

Contact: Phil Renaud **Phone:** (613) 724-3327
FAX: (613) 728-3404

Other Contacts: Sid Pyefinch **Phone:** (613) 523-3555

André Lambert **Phone:** (613) 728-3319

2. Site Plan

Please sketch of plan view and elevation. Indicate the overall dimensions, north arrow directions and ground floor, and typical floor and roof layout. (From architectural drawings or site-plans if available.)

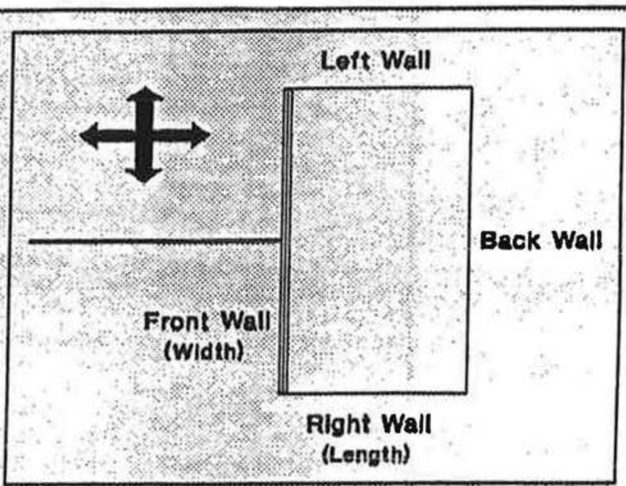
Assign Orientations:

Front Wall: East
Right Wall: North
Back Wall: West
Left Wall: South

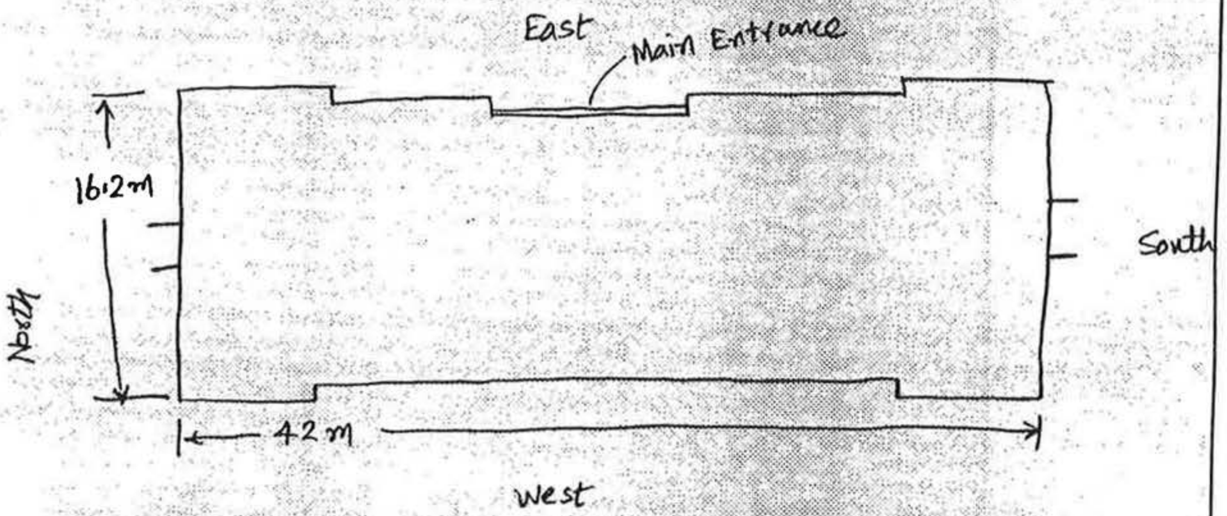
Dimensions:

Front Wall: 42 m
Right Wall: 16.2 m
Back Wall: 42 m
Left Wall: 16.2 m

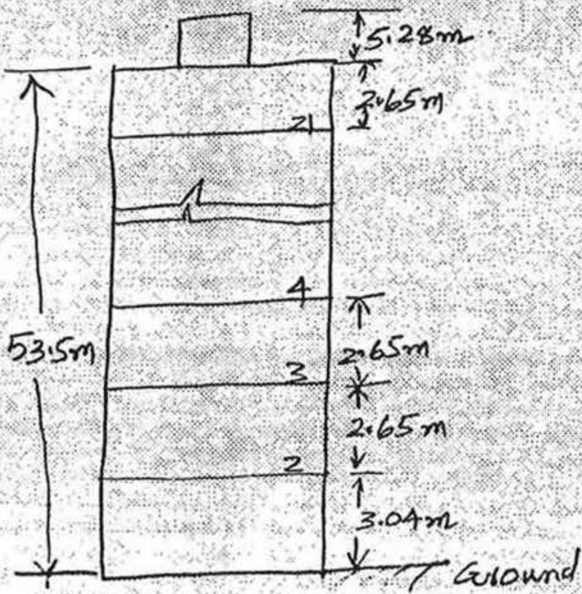
Height: Ground to roof = 53.5 m
Ground to Penthouse roof: 58.8 m



Building Dimensions and Directions



Site Plan (continued)



Building Dimensions and Areas (from drawings and plans if available)

Building Floor Area and Volume: Determine the total enclosed heated and unheated floor area of the building.

Heated Floor area: 14,290 m^2

Volume: 43515 m^3

Exposed Building Envelope Area: Determine the total building envelope area using the exterior dimensions, inclusive of walls, roof, windows (including frames), doors and exposed floors.

Walls:

main floor: 366.3 m^2

typical floor: 6291.1 m^2

Penthouse: 167.4 m^2

} includes windows & doors

Roof: 645.5 m^2

Total: 7470.3 m^2

3. Building Description and Occupancy

Year of Construction: 1976 **Number of Stories:** 21

Type of Construction: Concrete flat plate, no insulation at floor perimeter floors exposed to form balconies with no thermal break

Occupancy: @ 300 (total)

Number of Suites: 1 BR: 160 2 BR: 80 3 BR: ___ Other: ___ Total: 240

Wind Shielding: 2

(Consider the surroundings within a radius of the height of the building times 4 or so.)

1. Building in an open and flat terrain (very exposed - e.g., airport)
2. Suburban (exposed - cluster of low-rise buildings only)
3. Urban (mostly shielded - by other high-rise buildings)

Building Shape: 1
(plan view)

1. Rectangular or square
2. L shaped
3. C shaped
4. E shaped
5. T shaped
6. Other

Compass Orientation of Front Wall (degrees from North): ___ **or one of the below:** 7

1. North 2. NE 3. NW 4. South 5. SE 6. SW 7. East 8. West

Building Dimensions:
(from plans/sketch)

Width (Front Wall): 42 m
Length: 16.2 m
Height: 53.5 m

Total Floor Area:

Heated: 14290 m^2
Unheated: - m^2
Total: 14290 m^2

Building Volume:

Heated: 43515 m^3
Unheated: - m^3
Total: 43515 m^3

Building Exterior Envelope Area:
(above grade)

Walls: } 6657.4 m^2
Windows: } m^2
Roof: — 645.5 m^2
Doors: m^2
Other: 167.4 m^2
Total: 7470.3 m^2

4. Energy Use

4.1 Fuels by End Use

Space Heating: [1]
1. Electric Baseboard
2. Central heating by electric
3. Natural Gas
4. Oil or other

Space Cooling: [1]
1. Window air-conditioners (how many? [24])
2. Central cooling using electric chillers
3. Other
4. None

Make-up Air Heating: (Supplied to corridors) [2]
1. Electric Baseboard
2. Central heating by electric
3. Natural Gas
4. Oil or other

Make-up Air Cooling: (Supplied to corridors) [3]
1. Central cooling using electric chillers
2. Other
3. None

Hot Water: [1]
1. Electric
2. Natural Gas
3. Oil
4. Other

4.2 Electric Rates

Consult with local Hydro representative or check the current electric bill to indicate applicable format and electric rates.

Type of Service: [3] 1. Residential 2. General 3. Commercial 4. Time of Use & Large User 5. Other

				WINTER		SUMMER	
Energy:	First	250	kWh at	6.62	cents/kWh		cents/kWh
	Next	12250	kWh at	5.98	cents/kWh		cents/kWh
	Next	1989300	kWh at	4.33	cents/kWh		cents/kWh
	Balance		kWh at	2.68	cents/kWh		cents/kWh
Demand:	First	50	kW at	-	$/kW		$/kW
	~~Balance~~ Next	4950	kW at	4.10	$/kW		$/kW
	Balance			10.71	$/kW		

Peak Demand Hours: From 07:00 o'clock to 23:00 o'clock (Winter)
From 07:00 o'clock to 23:00 o'clock (Summer)

5. General Observations (From building plans, site-visit, discussion with building staff, supervisor, maintenance crew and owners)

Venting	- Hallway Pressurization ☑ Yes ☐ No - Stairwell Pressurization ☐ Yes ☑ No - Elevator Shaft Pressurization ☐ Yes ☑ No - Suite or Unit Exhaust Operable: ☑ Yes ☐ No In Use: ☑ Yes ☐ No
Moisture and Humidity (Please refer to moisture assessment section.)	-Basement and Ground Floor : none found -Exterior Walls - dry -Condensation on windows and walls : majority none -On the spot relative humidity measurements: Indoor and Outdoor - Outdoor RH : 38% Temperature : -5°C - Indoor RH : 21% temp. : 20°C
Air Quality	-Indoor air quality : -Occupants response : -mold and fungus deposits . - none
Thermal Comfort	-Complains about cold drafts many complains about cold drafts and very dry and static air -
Special Notes	Customer response to day-to-day building operation and maintenance, and problems related to the building. make-up air unit out for maintenance
Other	- Building very well maintained and clean. - had lighting & hot water retrofits

6. Exterior Survey

Please refer to the Air Sealing Assessment Procedure Guide for more information. The leakage Class depends on visual inspection of building component. There are three categories which can be assigned to Leakage Class: Tight, Average, and Loose. Leakage length represents the length of leakage path for the building component. The exterior survey is divided in to three sections: (i) ground floor and basement inspection, (ii) typical floor between 2nd and top floor, and (iii) penthouse and roof.

Tight - T
Average - A
Loose - L

6.1 Ground Floor (Exterior Envelope)

Building Component	Front Wall (East)		Right Wall (North)		Back Wall (West)		Left Wall (South)	
	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class
Windows								
Type 1: Fixed, Al frame Description: Size: 3'x6' Quantity: 3								
-Weatherstripping Perimeter per window: 5.5 m	16.5	T						
-Caulking perimeter: 5.5 m	16.5	T						
-Other								
Type 2: Horizontal Double Slider Description: Al. Window Size: 5'x2.5' Quantity: _____								
-Weatherstripping Perimeter per window: 6.1 m	6.1	A	12.2	A	6.1	A	12.2	A
-Caulking perimeter: 4.6 m	4.6	A	9.2	A	4.6	A	9.2	A
-Other								
Type 3: Horizontal Double Description: Slider Size: 4'x4' Quantity: _____								
-Weatherstripping Perimeter per window: 7.3 m	7.3	A	14.6	A	7.3	A	14.6	A
-Caulking perimeter: 4.9 m	4.9	A	9.8	A	4.9	A	9.8	A
-Other								

Building Component	Front Wall (East)		Right Wall (North)		Back Wall (West)		Left Wall (South)	
	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class
Type 4: ________ Description: Size: Quantity: ________								
-Weatherstripping Perimeter per window: ________ m								
-Caulking perimeter: _____ m								
-Other								
Doors								
Type 1: Patio door, Al Description: Double glazed Size: 9'x6' Quantity: ________								
-Weatherstripping Perimeter per door: 6.4 m	12.8	A			12.8	A		
-Caulking perimeter: 7.8 m	15.6	A			15.6	A		
-Other								
Type 2: Balcony Door Description: wood door Size: 3.5' x 6.5' Quantity: ________								
-Weatherstripping Perimeter per door: 5.5 m			5.5	L			5.5	L
-Caulking perimeter: 5.5 m			5.5	A			5.5	A
-Other								
Type 3: Metal door Description: Size: 3' x 6' Quantity: ________								
-Weatherstripping Perimeter per door: 5.5 m			5.5	L	7.3	A	5.5	L
-Caulking perimeter: 8.5 m			8.5	A	7.3	A	8.5	A
-Other								

Building Component	Front Wall (East)		Right Wall (North)		Back Wall (West)		Left Wall (South)	
	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class
Envelope Leakages								
Description:								
1. Canopy - 20'x20'	6.7	L						
2.								
3.								
4.								
5.								
6.								
7.								
8.								
Louvres and Exhaust Hatches								
-Size of exhaust louvre: 1'x1'	1.3	T	1.3	T	5.2	T	1.3	T
-Fresh air fan grilles:	3.3	T	~~3.3~~	T	13.2	T	3.3	T
-Laundry room exhaust:								
-Other								
Miscellaneous								
-Water hose bibs	# 2	T			# 2	T		
-Electric fixtures	# 2	T	# 1	T	# 3	T	# 1	T
-Fire hoses	# 3	T			# 2	T		
-Transformer entry door					7.3 m	T		
-Other								
-								
-								
Other Notes								
1. Window a/c	# 01	T			# 1	T		
2.								
3.								
4.								
5.								

6.2 Typical Floor (Between 2nd and Top Floor - Exterior Envelope)

Building Component	Front Wall (East)		Right Wall (North)		Back Wall (West)		Left Wall (South)	
	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class
Windows								
Type 1: Horizontal Double Description: Slider ~~Quantity~~ Size: 5'x2.5' -Weatherstripping Perimeter per window: 6.1 m -Caulking perimeter: 4.6 m -Other	24.4 18.4 ___	A T ___	12.2 9.2 ___	A T ___	24.4 18.4 ___	A T ___	12.2 9.2 ___	A T ___
Type 2: Horizontal Double Description: Slider ~~Quantity~~ Size: 4'x4' -Weatherstripping Perimeter per window: 7.3 m -Caulking perimeter: 4.9 m -Other	29.2 19.6 ___	A T ___	14.6 9.8 ___	A T ___	29.2 19.6 ___	A T ___	14.6 9.8 ___	A T ___
Type 3: ______ Description: Quantity: ___ -Weatherstripping Perimeter per window: ___ m -Caulking perimeter: ___ m -Other								
Doors								
Type 1: Balcony door Description: Quantity: ___ -Weatherstripping Perimeter per door: 5.5 m -Caulking perimeter: 5.5 m -Other	22 22 ___	A T ___	11 11 ___	A T ___	22 22 ___	A T ___	11 11 ___	A T ___

Building Component	Front Wall (East)		Right Wall (North)		Back Wall (West)		Left Wall (South)	
	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class	Leakage Length	Leakage Class
Type 2: ________								
Description:								
Quantity: ________								
-Weatherstripping Perimeter per door:________ m								
-Caulking perimeter: _____ m								
-Other								
Envelope Leakages								
Description:								
1. ________								
2. ________								
3. ________								
4. ________								
5. ________								
6. ________								
7. ________								
8. ________								
Louvres and Exhaust Hatches								
-Size of exhaust louvre: 1'x1'	6	T	4	T	6	T	4	T
-Fresh air fan grilles:								
-Other								
Miscellaneous								
-Electric fixtures	#4	T	#2	T	#4	T	#2	T
-Other								
-								
Other Notes								
1. Window a/c	#19	T	#3	T	#11	T	#6	T
2. ________								
3. ________								

6.3 Underground Parking and Basement Survey

Please refer to Guide for more information. Air leakage into a basement or underground parking may be controlled by sealing the perimeter envelope, above grade and below, or by sealing the separating elements that isolate the basement from the building above. It is always preferable to focus only on sealing the separating elements: the floor above, all penetrating shafts, stair doors, elevator vestibules etc. In such cases, only these separating elements need be assessed below.

	Description		Air-Sealing Method	Leakage Length (m)	Leakage Class
1.	**Basement Exterior Doors:** none				
	- Weatherstripping perimeter:	______ m.			
	- Caulking perimeter:	______ m.			
	Basement Exterior Windows: none				
	- Weatherstripping perimeter:	______ m.			
	- Caulking perimeter:	______ m.			
	Exterior Envelope Cracks above Grade Description:				
	1. Sill foundation	116 m.	Calking	116	T
	2.	______ m.			
	3.	______ m.			
	SEPARATING ELEMENTS				
2.	**Electrical Room**				
	1. Cable penetrations to the building	0.0008 m^2	caulk		
	2. wall perimeter & floor		Caulk	6.1 m	L
	3. Wall and ceiling		Caulk	7.7 m	L
3.	**Boiler Room**				
	1.				
	2.				
	3.				
4.					
	1. Elevator vestibule		Caulk	8 m	A
	2. Stairwell and door				
	3. Other				
	4.				

6.4 Mechanical Room, Penthouse and Roof Inspection

Please refer to Guide for more information. Air escaping the building through the mechanical room/penthouse may be controlled at the separation between the building and the room, or by attempting to seal the exterior envelope of a room, fan louvres etc. The former is almost always the more cost-effective line of attack. In such case, the assessor may ignore the following points on the penthouse envelope and focus only on the building roof and stairs.

Description	Air-Sealing Method	Leakage Length (m)	Leakage Class
Exterior walls and roof joint:			
1. Wall & roof	Caulk	116.4	A
2.			
3.			
Exhaust Fans and Penthouse Ventilation Louvres			
Floor Penetrations (building roof/penthouse floor):			
1. Pipe penetration	Caulk	0.008 m²	A
2. Cable penetration	Caulk	0.008 m²	A
3. Ducts	Caulk	0.008 m²	L
Stairs Connected to Penthouse (or Mechanical Room)			
1. Stairs to mechanical room	Caulk	15.3 m	L
2.			
Access Hatches at the Roof	Caulk	0.002 m²	T
Elevator Shafts			
1. Opening at the Cable Drive - 1 — 0.010 m²	Cover	0.01 m²	L
2. Opening at the Cable Drive - 2 0.010 m²	Cover	0.01 m²	L
3. m²			
Smoke Shafts None			
1. Opening area at the top m²			
2. m²			
Garbage Chute Hatches at the Roof			
1. Opening area at the top 0.015 m²	Cover	0.015 m²	L
2. m²			
Other			
1.			

7. Interior Survey

Air leakage paths through the building envelope should also be assessed from the inside: Entry and overhead doors, main entrance overhangs, laundry room exhaust vents, garbage room chute, smoke shafts, pipe penetrations, fire doors, perimeter baseboard heaters, elevator shafts and garbage room.

7.1 Ground Floor, Hallway, Stairwell, Elevator Shafts and Service Shafts: Leaks to Outdoors

	Description	Air-Sealing Method	Leakage Length (m)	Leakage Class
1.	**Ground Floor**			
	- Main entrance projections 10mm gap under main entrance	accounted elsewhere		
	- Other			
	Envelope Leaks			
	1. Discontinuity on West wall	Caulk	5.5	L
	2.			
	3.			
	Service Rooms			
	1. wall & floor joint	Caulk	5.5m	L
	2.			
	3.			
	Halls			
	1.			
	2.			
	3.			
	Other			
	1. Baseboard heaters	Caulk	$0.002 m^2$	
	2.			
	3.			

(Interior Survey: Ground Floor and Shafts - Continued)

2. Elevator Shafts:

Leaks to outdoor: 0.023 m²

Other leaks: ______ m²

______ m²

Garbage Chutes:

Leaks to outdoor: 0.093 m²

Other leaks: pipes 0.001 m²

______ m²

Stairwells:

Exposed opening: 2 x 0.008 m²

______ m²

Envelope leaks:

1. ______ ______ m ______ Class ______ width ______ m²
2. ______ ______ m ______ Class ______ width ______ m²
3. ______ ______ m ______ Class ______ width ______ m²
4. ______ ______ m ______ Class ______ width ______ m²

Fire Shafts (or Smoke Shafts):

Leaks to outdoor: ______ m²

Other leaks: ______ m²

______ m²

7.2 One Bedroom Suite Inspection (Leaks to outdoor)

	Description	Air-Sealing Method	Leakage Length (m)	Leakage Class
1.	**Interior Inspection**			
	Baseboard heater: 0.003 m^2	Caulk	0.003 m^2	L
	Leaks around pipes and cable penetrations: 6 pipes + cables m^2	Caulk		A
	Leakage around exhaust fan ducts through exterior envelope: ________ m^2			
	Envelope leaks which are not included elsewhere:	______	______	______
	1. ________________	______	______	______
	2. ________________	______	______	______
	3. ________________	______	______	______
	4. ________________	______	______	______

2. **Depressurization test:** If the unit is depressurized using the blower door fan, note the various air leakage paths using smoke pencils or tracers. The air leakage from exterior envelope, party walls, exhaust fan, and pipe penetrations should be noted as follows:

1. Baseboard heater on exterior wall: Is the leak from baseboard heater an outdoor air leak or coming from party walls? If the air leak is from the party wall then the baseboard leak may not be a through envelope leak. Outdoor leak
2. Floor and exterior wall joints few minor leaks, otherwise tight
3. Ceiling and exterior wall joints tight
4. Balcony – few leaks, mostly tight
5. Window / wall joint – partially leaky
6. Door and wall joint – partially leaky
7. Other observations

7.3 Two Bedroom Suite Inspection (Leaks to outdoor)

	Description	Air-Sealing Method	Leakage Length (m)	Leakage Class
1.	**Interior Inspection**			
	Baseboard heater: 0.006 m²	Caulk	0.006m²	L
	Leaks around pipes and cable penetrations: 6 pipes + cables m²	Caulk		A
	Leakage around exhaust fan ducts through exterior envelope: ______ m² (accounted)			
	Envelope leaks which are not included elsewhere:	______	______	______
	1. ______	______	______	______
	2. ______	______	______	______
	3. ______	______	______	______
	4. ______	______	______	______

2. **Depressurization test:** If the unit is depressurized using the blower door fan, note the various air leakage paths using smoke pencils or tracers. The air leakage from exterior envelope, party walls, exhaust fan, and pipe penetrations should be noted as follows:

1. Baseboard heater on exterior wall: Is the leak from baseboard heater an outdoor air leak or coming from party walls? If the air leak is from the party wall then the baseboard leak may not be a through envelope leak. leaks from outdoor
2. Floor and exterior wall joints generally tight with few minor leaks
3. Ceiling and exterior wall joints tight
4. Balcony - tight with few minor leaks
5. Window / wall joint partially leaky
6. Door and wall joint partially leaky
7. Other observations

7.4 Three Bedroom Suite Inspection (Leaks to outdoor) none

	Description	Air-Sealing Method	Leakage Length (m)	Leakage Class
1.	**Interior Inspection** Baseboard heater: _______ m^2 Leaks around pipes and cable penetrations: _______ m^2 Leakage around exhaust fan ducts through exterior envelope: _________ m^2 Envelope leaks which are not included elsewhere: 1. ____________________ 2. ____________________ 3. ____________________ 4. ____________________	 _______ _______ _______ _______ _______	 _______ _______ _______ _______ _______	 _______ _______ _______ _______ _______
2.	**Depressurization test:** If the unit is depressurized using the blower door fan, note the various air leakage paths using smoke pencils or tracers. The air leakage from exterior envelope, party walls, exhaust fan, and pipe penetrations should be noted as follows: 1. Baseboard heater on exterior wall: Is the leak from baseboard heater an outdoor air leak or coming from party walls? If the air leak is from the party wall then the baseboard leak may not be a through envelope leak. 2. Floor and exterior wall joints 3. Ceiling and exterior wall joints 4. Balcony 5. Window / wall joint 6. Door and wall joint 7. Other observations			

8. Miscellaneous Data

	Description	Air-Sealing Method	Leakage Length (m)	Leakage Class
1.		______ ______ ______ ______ ______ ______ ______	______ ______ ______ ______ ______ ______ ______	______ ______ ______ ______ ______ ______ ______
2.		______ ______ ______	______ ______ ______	______ ______ ______
3.		______ ______ ______	______ ______ ______	______ ______ ______
4.		______ ______ ______ ______	______ ______ ______ ______	______ ______ ______ ______

AIR SEALING ASSESSMENT PROCEDURE FOR HIGH-RISE RESIDENTIAL BUILDINGS (Electrically Heated Eight Stories or Higher)

Part B: Estimation of Uncontrolled Air Leakage

The estimation procedure includes the following sections:

- Determination of air leakage area
- Determination of pressures due to stack, wind and mechanical ventilation
- Calculation of air leakage flow rates at different heights
- Estimation of net air leakage component
- Estimation of savings in peak electric heating demand and energy consumption due to air-sealing
- Determination of air-sealing priorities

1. Weather Data

The peak air infiltration occurs during the peak winter design conditions. The winter design conditions can be obtained from Table ?? of Guide or National Building Code. (For example, the winter design temperature for Toronto is -18 C, mean wind speed for air leakage calculations is 11.5 m/s and the heating degree days are 3646 C-days.) The field inspection visit provides information on the surrounding wind shielding conditions.

Location	Ottawa
Winter Design Temperature 2.5%, °C	-18°C
Mean Wind Speed, m/s	12.5
Wind Shielding and Terrain Type	Suburban
Heating Degree Days (below 18 °C)	4634

2. Calculation of Air Leakage Area

Determine the air leakage area using the field inspection data.

Storey	Component	Front Wall			Right Wall			Back Wall			Left Wall			Total Leakage
		Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Area, m^2 5+8+ 11+14
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	
Ground	**Windows**													
-exterior	Type 1 Fixed	16.5 T 16.5 T	0.00013	0.0043										
envelope	Type 2 Slider	6.1 A 4.6 A	0.0008	0.0085	12.2 A 9.2 A	0.0008	0.0017	6.1 A 4.6 A	0.0008	0.0085	12.2 A 9.2 A	0.0008	0.0017	
	Type 3 Slider	7.3 A 4.9 A	0.0005	0.0061	14.6 A 9.8 A	0.0005	0.0122	7.3 A 4.9 A	0.0005	0.0061	14.6 A 9.8 A	0.0005	0.0122	
	Type 4													
	Total			0.0189			0.0139			0.0147			0.0139	0.0614
	Doors													
	Type 1 Sliding	12.8 A 15.6 A	0.0007	0.0198				12.8 A 15.6 A	0.0007	0.0198				
	Type 2 Wood door				5.5 L 8.5 A	0.0012 0.0007	0.0126	7.3 A 7.3 A	0.0007	0.0102	5.5 L 8.5 A	0.0012 0.0007	0.0126	
	Type 3													
	Total			0.0198			0.0126			0.0290			0.0126	0.064
	Envelope Leakages													
	1. Canopy	6.7 A	0.0004	0.00268										
	2. Wall perimeter	6.1 A 7.7 A	0.0003	0.00552										
	3. Sill found	116 T	0.0002	0.0232										
	4.													
	5.													
	Total			0.0314										0.0314

Storey	Component	Front Wall			Right Wall			Back Wall			Left Wall			Total Leakage Area, m² 5+8+11+14
		Leakage Length & Class	Assign Leakage Value	Leakage Area (m²)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m²)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m²)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m²)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	
Ground	Miscellaneous													
-exterior	Exhaust louvres	1.3 T	0.0004	0.00052	1.3 T	0.0004	0.00052	5.2 T	0.0004	0.0021	1.3 T	0.0004	0.00052	
envelope	Fresh air fan grilles	3.3 T	0.0004	0.00132	3.35	0.0004	0.00132	13.2 T	0.0004	0.0052	1.3 T	0.0004	0.00132	
	Laundry exhaust							1 T	0.0004	0.0004				
	Water hose bibs	#2 T	0	0				#2 T	0	0				
	Electric fixtures	#2 T	0	0	#1 T	0	0	* 3 T	0	0	#1 T	0	0	
	Fire hoses	#3 T	0	0				* 2 T	0	0				
	Other 1. Window A/C	# 1 T	0	0				# 1 T	0	0				
	2. Wall/floor				11 A	0.0004	0.0044							
	3. baseboard	# 6	A	0.0048										
	Total			0.00664			0.00624			0.00736			0.00184	0.02208
	Total Leakage Area (m²)													0.1789

Storey	Component	Front Wall			Right Wall			Back Wall			Left Wall			Total Leakage Area, m² 5+8+ 11+14
		Leakage Length & Class	Assign Leakage Value	Leakage Area (m²)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m²)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m²)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m²)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	
Typical	**Windows**													
floor	Type 1 Slider	24.4 A 18.4 T	0.0005 0	0.0122	12.2 A 9.2 T	0.0005	0.0061	24.4 A 18.4 T	0.0005	0.0122	12.2 A 9.2 T	0.0005 0	0.0061	
between	Type 2 Slider	29.2 A 19.6 T	0.0005 0	0.0146 0	14.6 A 9.8 T	0.0005 0	0.0073	29.2 A 19.6 T	0.0005 0	0.0146	14.6 A 9.8 T	0.0005 0	0.0073	
2nd and	Type 3													
top	Type 4													
floor	Total			0.0268			0.0134			0.0268			0.0134	0.0804
-exterior	**Doors**													
envelope	Type 1	22 A 22 T	0.0005 0	0.011	11 A 11 T	0.0005 0	0.0055	22 A 22 T	0.0005 0	0.011	11 A 11 T	0.0005 0	0.0055	
	Type 2													
	Type 3													
	Total			0.011			0.0055			0.011			0.0055	0.033
	Envelope Leakages													
	1.													
	2.													
	3.													
	4.													
	5.													
	Total													

Storey	Component	Front Wall			Right Wall			Back Wall			Left Wall			Total Leakage Area, m² 5+8+11+14
		Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	Leakage Length & Class	Assign Leakage Value	Leakage Area (m^2)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	
Typical	Miscellaneous													
floor	Exhaust louvres	6	0	0	2	0.0004	0.0008	6	0	0	2	0.0004	0.0008	0.0016
between	Fresh air fan grilles													
2nd and	Laundry exhaust													
top	Water hose bibs													
floor	Electric lamps	#4	0	0	#2	0	0	#4	0	0	#2	0	0	0
-exterior	Fire hoses													
envelope	Other 1. window A/C	#19	0	0	#3	0	0	#11	0	0	#6	0	0	
only on 21st top floor	2.	116.4 A	0.0004	0.04654										
	3.	15.3 L	0.0008	0.0124										
	Total			0.0589										0.0016 2nd to 0.0605 top
	Total Leakage Area (m^2)													0.115 2nd & 0.0605 top.

Shafts Leakage Area

Leaks connecting to outdoors or to top and bottom zones only.

Storey	Elevator Shafts Leakage Area, m²			Stairwells Leakage Area, m²		Service Shafts Leakage Area, m²	Garbage Chute Leakage Area, m²	Smoke Shafts Leakage Area, m²	Total Leakage Area, m²
	Elevator - 1	Elevator - 2	Elevator - 3	Stairwell - 1	Stairwell - 2				
Ground Floor and Basement	0.008	0.008		0.008	0.008		0.094		0.126
2nd to Top Floor*									
Roof and Penthouse	0.010	0.010		0.008	0.008		0.015		0.051
Total Leakage Area, m²									0.177

* Only where shafts form part of exterior envelope.

3. Total Leakage Area Summation

Storey	Windows (m^2)	External Doors (m^2)	Building Envelope (m^2)	Elevator & Service Shafts (m^2)	Miscellaneous (m^2)	Total Leakage Area (m^2)	Comments
Ground and Basement	0.0614	0.064	0.034	0.126	0.0221	0.3075	
2nd to Top	0.0804 ×20	0.033 ×20	–	–	0.0016 ×20	2.3	
Roof and Penthouse	–	–	0.0597	0.051		0.1107	
Total Leakage Area	1.669	0.724	0.0937	0.177	0.0541	2.718	
Percentage of Leakage Area	61.4	26.6	3.4	6.5	2.0		

4. Calculation of Air Leakage Rates

4.1 Calculation of Stack Pressure, Ps

Stack pressure, Ps, can be obtained using the following equation:

$$P_s = \rho g (h1 - h2)[T_i - T_o]/T_o * TDC$$

where, Ps = pressure difference due to stack effect, Pa
rho = air density, kg/m^3 (use 1.18)
T_i = indoor temperature, K (use 293 K = 273 + 20 C)
T_o = outdoor temperature, K (winter design condition)
h2 = building height at which stack pressure is being determined, m
h1 = building height at which neutral pressure plane occurs (assume mid-height of building), m
TDC = Thermal Draft Coefficient (refer Table ?? of Guide)

The Table ?? provides value of stack pressures for four residential apartment buildings. These values can be used for first trial calculations.

4.2 Calculation of Wind Pressure, Pw

The wind pressure is given as,

$$P_w=(\rho C_p V_H^2)/2$$

where, Pw = average surface pressure due to wind, Pa
C_p = surface pressure coefficient, varies from 0.25 to 0.35 (refer Table ??)
V_H = wind speed, m/s

The wind speed, V_H, can be determined using the following equations:

$$V_H=A_o*V_{met}*(H/10)^a$$

where, H = height at which wind pressure is to be determined, m
V_{met} = mean wind speed obtained from metrological data, m/s
A_o, a = coefficients dependent on terrain and wind shielding (refer Table ?? of Guide)

Calculations:

1. Determine the following to calculate stack pressure distribution:

S1 = $[T_i - T_o]/T_o$ for example, for an indoor temperature of 20 C and outdoor temperature of -18 C, value of S1 is [(273+20)-(273+(-18))]/(273+(-18)) = 0.149

S1 = [(273+20) - (273 + (-25))]/(273+(-25)) = 0.149

S2 = density x gravitational constant = 1.18 * 9.81 = 11.58

S2 = 11.58

SC = S1 * S2 * TDC for example, 0.149 * 11.58 * 0.8

SC = 0.149 x 11.58 x 0.7 = 1.207

h1 = mid height of the building, m e.g. for a 80 m tall building, h1 = 40 m

h1 = 29 m

2. Determine the following to calculate wind pressure distribution:

W1 = A_o * V_{met} for example, for a Toronto building in suburban terrain (A_o = 0.60 and V_{met} = 11.5 m/s), W1 = 6.9

W1 = 0.60 x 12.5 = 7.5

W2 = density * pressure coefficient / 2 = 1.18 * 0.25 / 2 = 0.148

W2 = 1.18 x 0.20 /2 = 0.118

4.3 Calculation of Air Leakage Rate

The air flow rate through a leakage area A is defined as,

$$Q = C_d * A * \sqrt{2 \Delta P / \rho}$$

where, Q = Air flow rate, m^3/s

C_d = discharge coefficient for the leakage path, varies from 0.65 to 0.85 (use 0.7)

A = Leakage area, m^2

rho = density, kg/m^3 (use 1.18)

ΔP = pressure difference across building envelope, Pa

4.4 Steps

The following forms are used to determine the air leakage rate at each floor. Steps are as follows:

Step 1. Enter the height of each floor measured from the ground.

Step 2. Enter the air leakage area from the previous sections.

Step 3. Calculate the wind pressure *Pw* at each floor level using the equations as described above. The average wind pressure acting on the building envelope will induce air leakage in the building.

Step 4. Determine the air-flow due to wind *Qw* using the wind pressure *Pw*.

Step 5. First assume that the neutral pressure plane occurs at the mid height of the building. The value of *h1* will be *(height of the building / 2)*.

Step 6. Determine the stack pressure *Ps* using the equations as described above. The positive value of stack pressure indicate air infiltration into the building and negative values indicate exfiltration from the building.

Step 7. Determine the air-flow due to stack *Qs* using the absolute value of stack pressure *Ps*. Assign the algebraic sign to this air-flow as that of *Ps*.

Step 8. Determine the total air-flow *Q* for the floor, using the quadrature equation as defined above. Assign the algebraic sign to this air-flow as that of air-flow due to stack *Qs*.

Step 9. Add the air infiltration flows *Qi* (positive values of *Q*) and air exfiltration flows *Qo* (negative values of *Q*). Compare *Qi* and *Qo*. If the difference is more than 5% *((Qi-Qo)/Qi)*, repeat the calculations from Step 5 by shifting the height of neutral pressure plane. If *Qi* is greater than *Qo*, then assume the neutral pressure plane one floor below than before. If *Qi* is smaller than *Qo*, then assume the neutral pressure plane one floor above than before. Repeat these calculations.

Step 10. The net infiltration or exfiltration flow (*Qi* or *Qo*) is the uncontrolled air leakage rate.

(Please refer to illustrated example in the Guide)

Calculation of Air Leakage Rate

Instructions:	1. Height of building measured from above ground	2. Leakage area as calculated from Table ??.	3. Wind Pressure Calculations:	4. Stack Pressure Calculations	5. Air-flow Calculations
			- $W1 = A_o * V_{met}$ 7.5 - $W2$ = air density * Cp / 2 = 1.18*0.25/2 = 0.148 = 1.18×0.2/2 = 0.118	- h1 is height of neutral pressure plane measured from the ground - $S1 = [T_i - T_o]/T_o$ - $S2 = 1.18 * 9.81 = 11.58$ - $SC = S1 * S2 * TDS$	- $Q1 = 0.7*(2/1.18)^{0.5} = 0.91$ - $Qs = A * Q1 * (\lvert Ps \rvert)^{0.5}$ - $Qw = A * Q1 * (Pw)^{0.5}$ - $Q = ((Qs)^2 + (Qw)^2)^{0.5}$ - Assign proper algebraic sign to *Qs* and *Q* depending on *Ps*.

h1= 30m.

Storey	Height h2 m	Leakage Area (m^2) *A*	Wind Pressure, *Pw*, (Pa)		Stack Pressure, *Ps*, (Pa)		Air-flow Calculations		
			W3 = (W1*(h2/10)ⁿ)	W2*(W3)² Pw	Height Difference (h1-h2)	SC*(h2-h1) Ps	Air-flow due to Stack (m^3/s) *Qs*	Air-flow due to Wind (m^3/s) *Qw*	Total air-flow (m^3/s) *Q*
Ground	0.100	0.308		0.55		−32.4			−1.82
~~1~~ 2	3.035	0.115		3.72		−29.1			−0.67
~~2~~ 3	5.690	0.115		5.3		−26.1			−0.66
~~3~~ 4	8.344	0.115		6.56		−23.2			−0.64
~~4~~ 5	10.998	0.115		7.65		−20.2			−0.63
~~5~~ 6	13.653	0.115		8.64		−17.3			−0.60
~~6~~ 7	16.307	0.115		9.54		−14.3			−0.58
~~7~~ 8	18.961	0.115		10.38		−11.3			−0.55
~~8~~ 9	21.615	0.115		11.2		−8.3			−0.52
~~9~~ 10	24.270	0.115		11.9		−5.4			−0.49
~~10~~ 11	26.924	0.115		12.6		−2.4			−0.46
~~11~~ 12	29.578	0.115		13.3		0.6			0.44
~~12~~ 14	32.233	0.115		13.9		3.5			0.50

Storey	Height h2	Leakage Area (m^2) *A*	Wind Pressure, *Pw*, (Pa)		Stack Pressure, *Ps*, (Pa)		Air-flow Calculations		
			$W3 = (W1*(h2/10)^a)$	$W2*(W3)^2$ P_W	Height Difference (h1-h2)	SC*(h2-h1) P_S	Air-flow due to Stack (m^3/s) *Qs*	Air-flow due to Wind (m^3/s) *Qw*	Total air-flow (m^3/s) *Q*
~~13~~ 15	34.887	0.115		14.6		6.5			0.54
~~14~~ 16	37.541	0.115		15.2		9.5			0.59
~~15~~ 17	40.155	0.115		15.8		12.4			0.63
~~16~~ 18	42.850	0.115		16.4		15.4			0.67
~~17~~ 19	45.504	0.115		16.9		18.4			0.70
~~18~~ 20	48.158	0.115		17.5		21.3			0.74
~~19~~ 21	50.813	0.115		18.0		24.3			0.77
~~20~~ 22	53.467	0.115		18.6		27.3			0.80
Penthouse	58.75	0.111		19.6		33.2			0.83
22									
23					Total = 14.8 m^3/s.				−0.431
24								Air infiltration flow =	5.9 m^3/s
25					Without iterations = $\frac{14.8}{2.5}$		= 5.9 m^3/s		
26									
27									
28									
29									
30									
								Total Air Flow (m^3/s)	

4.5 Air Leakage Rate

The air infiltration rate in this building at peak design conditions is 5.9 m^3/s or 5900 L/s.

5. Calculations of Reductions in Peak Demand and Energy Consumption

The peak heating due to infiltration at the design weather conditions can be obtained by

$$HL_{infil}=Q_i \rho C_p \Delta T$$

where,

HL_{infil}	=	heat load due to air infiltration, kW
Q_i	=	air inflow rate, m^3/s
ρ	=	air density, kg/m^3 (about 1.18)
C_p	=	specific heat of air, kJ/(kg C) (about 1.0)

Using standard air ρ = 1.18 kg/m^3, and C_p = 1.0 kJ/(kg C), the above equation simplifies to:

$$q=1.18Q_i(T_i-T_o)$$

Infiltration air-flow Qi = 5.9 m^3/s
Indoor and outdoor temperature difference is 38 °C.

Peak Heating Load, HL_{infil} = 1.18 * Qi * (Ti - To)

Peak Heating Load = 1.18 * 5.9 * (293-255) kW

264 kW @ 50% of space heating.

The above heat load is the total demand due to uncontrolled infiltration. Total air-sealing of the building would reduce the peak heat demand by this amount, but that is not practicable. Cost effective air-sealing will result in reducing a substantial portion. The reduction in heat load will be proportional.

For most high-rise residential the air-sealing effectiveness, $S_{effectiveness}$, may vary from 20% to a maximum of 40% depending on the extent of air sealing. The assessor's judgement will normally be in that range.

For high-rise buildings consider the following air-sealing effectiveness

Loose construction, $S_{effectiveness}$ = 0.40
Average construction, $S_{effectiveness}$ = 0.32
Tight construction, $S_{effectiveness}$ = 0.25

The reduction in peak heating demand due to air sealing will then be:

$$HL_{Infil(Reduction)} = S_{effectiveness} * HL_{Infil}$$

$$= 0.32 \times 264 = 84.5 \text{ kW}$$

The $HL_{Infil(Reduction)}$ should be utilized in determining the incentive for air-sealing costs.

The energy reduction in energy consumption is given as following:

$$E = (HL_{Infil(Reduction)} * DD * C) / (\Delta T)$$

where, E = Annual reduction space heating energy, kWh
DD = Annual heating degree days, (C - days)
ΔT = Design temperature difference, C (*Ti* - *To*)
C = C-factor, Credit factor, hours/day

The value of degree days is obtained from the weather data. The C-factor allows credits for internal heat gains due to sun, lights, people, equipment, night setback and for the reduced mechanical ventilation. With these internal gains, only a fraction of the full load energy is actually required. This fraction is multiplied by 24 (hours/day) produces the "C" factor. For high-rise residential buildings, the C-factor varies from 14 to 18 hours/day. [Refer Guide for more information.]

Annual Heating Degree Days, *DD* = 4634 °C-days
Design Temperature Difference, ΔT = (*Ti* - *To*) = (293 - 255) = 38
C-factor = 14 hours/day

$$E = (HL_{Infil(Reduction)} * DD * C) / (\Delta T)$$

$$= 84.5 \times 4634 \times 16 / 38$$

$$= 164{,}870 \text{ kWh}$$

6. Ranking of Air-Sealing Priorities

6.1 Building Components

Based on component leakage area, the reductions in peak demand can be roughly ranked as follows:

Building Component	Percentage of Leakage Area (from page B-7)	Potential Demand Reduction, $HL_{Infil(Reduction)}$	Demand Reduction, kW	Ranking (ascending)
Exterior Windows	61.4	84.5	51.9	1
Exterior Doors	26.6	"	22.5	2
Building Envelope	3.4	"	2.9	4
Elevators & Shafts	6.5	"	5.5	3
Miscellaneous	2.0	"	1.7	5

6.2 Leakage Area Distribution

Plot a distribution of air flows at each floor level on the attached graph. The leakage rates at the basement, ground, top floor and penthouse are generally higher than other floors. From the graph determine the predominant floors where air leakage rates are higher than other floors. If only these floors are air-sealed than it would result in reducing a substantial component of air leakage in the building. It has been established with several sensitivity analyses that, as a general rule, for a building the top 1/3rd and bottom 1/3rd height contributes more than 75 to 90% of total air leakage in the building (for example, for a 30 storey building, the bottom 10 floors and top 10 floors). From the graph, determine the following:

Below Neutral Pressure Plane (below the floor where air leakage rate is zero):

- Determine the total air infiltration rate (sum of all air leakage rates), *Qi*: 5.9 m^3/s
- Determine the air leakage rate for the bottom 1/3rd floor levels, *Qi(bottom 1/3)*: 4.5 m^3/s
- Ratio of *Qi(bottom 1/3) / Qi* = 4.5/5.9 = 0.76 (B-6.2A)

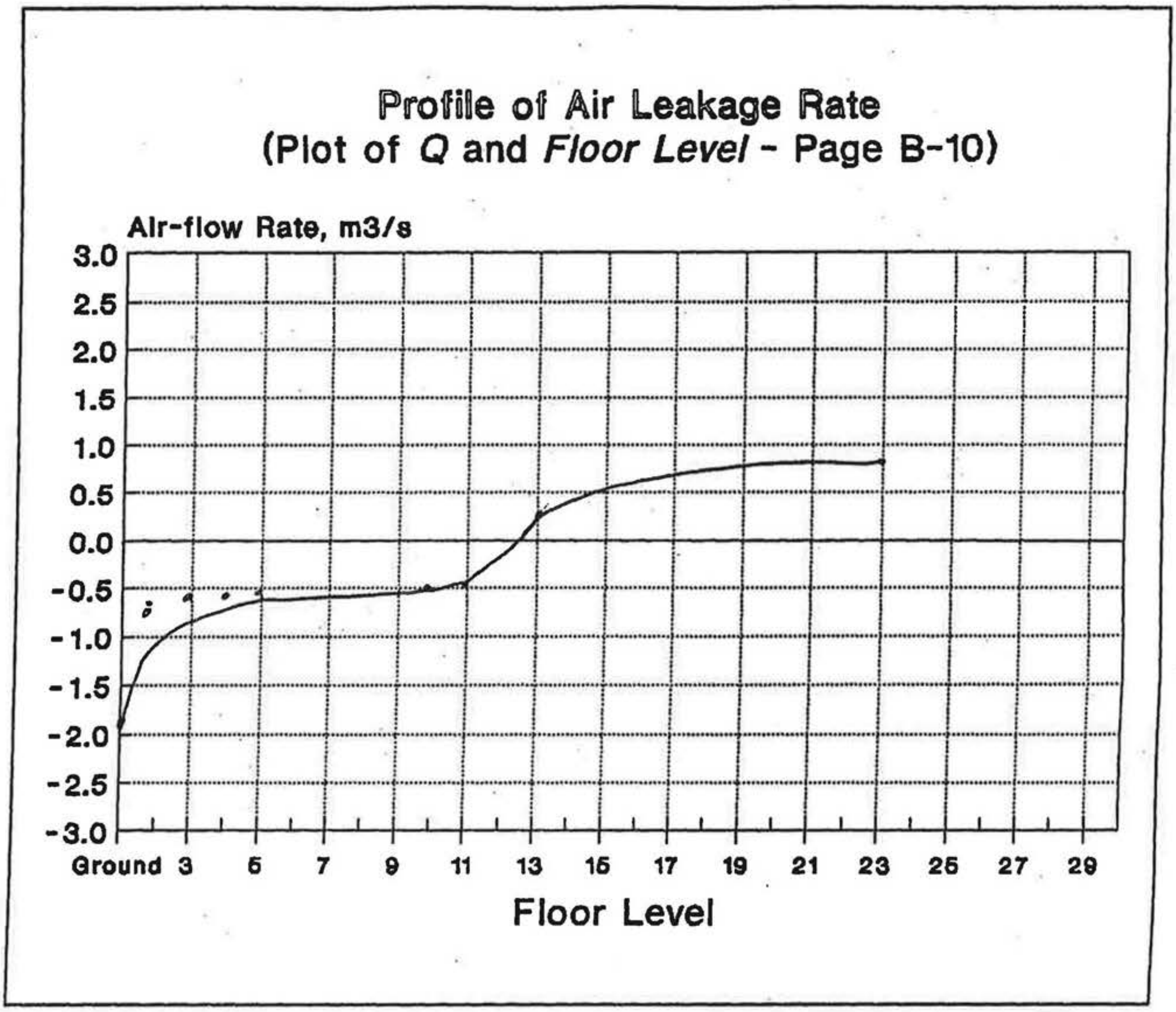
Above Neutral Pressure Plane (above the floor where air leakage rate is zero):

- Determine the total air exfiltration rate (sum of all air leakage rates), *Qo*: 5.9 m^3/s
- Determine the air leakage rate for the top 1/3rd floor levels, *Qo(top 1/3)*: 5.0 m^3/s
- Ratio of *Qo(top 1/3) / Qo* = 5.0/5.9 = 0.86 (B-6.2B)

- Ratio (B-6.2A) or (B-6.2B) is in the range of 0.7 or more: ☑ Yes ☐ No

If yes, the air-sealing of bottom 1/3rd and top 1/3rd height of building offers the potential peak demand reduction of $HL_{Infil(Reduction)}$ * *maximum of (B-6.2A or B-6.2B)* = 84.5X0.76 kW.

= 64.2 kW


Profile of Air Leakage Rate
(Plot of Q and Floor Level - Page B-10)
Air-flow Rate, m3/s
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
Ground 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Floor Level

APPENDIX C: UNIT COST OF AIR-SEALING MEASURES AND COST-BENEFIT ANALYSIS

FOCUSED COST SURVEY OF AIR-SEALING COSTS

Air Sealing Measures

Exterior Doors:	$ 80.00	each
Commercial Doors (Set of 2)	$250.00	each
Overhead Exterior Doors (Wood Fascia)	$ 65.00	lineal metre
Fire Doors	$ 80.00	each
Interior Window Caulking	$ 4.30	lineal metre
Interior Door Caulking	$ 4.30	lineal metre
Interior Baseboard Caulking	$ 16.00	lineal metre
Window / Patio Door weatherstripping	$ 32.50	lineal metre
Baseboard Heaters	$ 20.00	each
Wall electric outlets	$ 3.00	each

This data was collected by Ontario Hydro in July 1991.

September 1991

COST-BENEFIT ASSESSMENT OF AIR LEAKAGE CONTROL MEASURES IN HIGH-RISE RESIDENTIAL BUILDINGS

The air leakage control measure offers an excellent opportunity for energy conservation and peak power demand savings in high-rise buildings across Ontario. Several multi-residential building owners and building managers have shown a great interest in implementing the air sealing measure in their buildings by taking advantage of Ontario Hydro's several cost incentive program(s).

The two case studies, attached herewith, show the cost-benefit assessment of air leakage control measures in high-rise buildings. These buildings were part of a demonstration project for air leakage control sponsored by Ontario Hydro. The total cost of assessment, air-sealing, quality control and monitoring was borne by Ontario Hydro.

The intent of the cost-benefit analysis is to present to building owners situations which are financially of a similar order of magnitude, and to demonstrate the benefits acquired from the implementation of air leakage control retrofits.

AIR LEAKAGE CONTROL OF 251 DONALD STREET BUILDING

Building Description

The 251 Donald Street building is a 21-storey apartment tower, located in Ottawa, operated for senior citizens and owned by the Ottawa-Carleton Regional Housing Authority (OCRHA). The building is comprised of 240 suites. The total floor area of heated space is 14,290 m^2 (153,760 ft^2). The total energy bill for the year 1990 was $134,900. The energy consumption of this building was continuously monitored from November 1990 to July 1991 to determine the impact of the air-sealing measures.

Air-Sealing of Building

The air-sealing measure was implemented on this building during the month of January 1991 to reduce the peak electric demand and energy consumption. Building envelope, all windows, exterior doors, elevator shafts, and visual gross leaks were sealed. It should be noted that the total cost of assessment, air-sealing and monitoring was borne by Ontario Hydro. Air leakage assessment and leakage characterization was done twice to meet certain research objectives such as development of a reliable assessment procedure. Indoor air quality tests performed before and after air sealing showed that there was no negative impact on the general conditions of comfort and air quality in the building. The following presents the cost calculation of implementing the air-sealing measure.

Cost of Assessment (Feasibility)

Building inspection, assessment and energy audit:	$ 4,500	(The actual cost was higher because of research element. The stated cost represents a typical assessment cost.)
Infra-red thermography, suite fan tests and air leakage characterization:	$ 2,000	(typical)

Implementation

Air-sealing:	$54,816	(actual)
Inspection and quality control:	$ 2,400	(typical)
Total Cost of Air-Sealing Measure	**$63,716.**	

Reductions in Energy Consumption Costs

Monitored results showed the following energy savings:

Reduction in annual energy consumption:	196,500 kWh (@ 7.5% of total)
Reduction in monthly peak demand:	85 kW during the months of December, January and February and of at least 50 kW in the months of November, April and May.

Energy cost reductions at 1990 rate: 196500 kWh x $0.0433/kWh = $8,500.
Demand cost reductions at 1990 rate: 85 kW x 3 months x $4.10/kW + 50 x 3 x 4.10 = $1,660.
Total reduction in billing due to air-sealing is $10,160 which is approximately 7.5% of the total 1990 electric bill for the building.

Simple Payback Analysis

The simple payback of the air-sealing measures to building owners, without considering any financial incentives, is 6.3 years ($63716/$10160).

The air sealing work to improve the building envelope qualifies for Ontario Hydro's incentive program. Ontario Hydro generally pays the full cost of the feasibility study. The incentive for the reduction in peak heating demand during winter months is calculated as up to $500/kW or fifty percent of air sealing costs, whichever is less.

The building owner's financial commitment will be as follows:

Feasibility study:			$6500
	Ontario Hydro	-	$6500
	Building Owner		$ 0
Air sealing, inspection and quality control:			$57,216
	Ontario Hydro	-	$28,608 (50% of total cost)
	Building Owner		$28,608
Total costs to the building owner:			**$28,608**

Based on energy savings, the simple payback period is 2.8 years ($28608/$10160).

Other Points

It should be noted that the above analysis presents the cost calculations based on 1990 electricity rates. The 1991 rates are approximately seven percent higher, and the 1992 rates are expected to increase more than 10%. It is our belief that the unit cost of air sealing may remain the same for a year or two due to competition and market forces. A cost-benefit assessment should consider these situations.

AIR LEAKAGE CONTROL OF BRIDLEVIEW YORK CONDOMINIUM

Building Description

The Bridleview York Condominium (YCC 449) is a 10-storey apartment building with 95 suites. It is located in Toronto. This is a freehold condominium apartment building managed and maintained by Gelco Management Services Limited. The total floor area of heated space is 9,825 m^2 (105,720 ft^2). Each suite is provided with electric baseboard heaters for space heating. Natural gas is utilized for hot water and for heating the building make-up air. The total electrical energy bill for the year 1989-90 was $92,546. The energy consumption of this building was continuously monitored from November 1990 to July 1991 to determine the impact of the air-sealing measures.

Air-Sealing of Building

The air-sealing measure was implemented on this building during the month of December 1990 to reduce the peak electric demand and energy consumption. The building envelope, all windows, exterior doors, elevator shafts, and visual gross leaks were sealed. It should be noted that the total cost of assessment, air-sealing and monitoring was borne by Ontario Hydro. Air leakage assessment and leakage characterization was done several times to meet certain research objectives such as development of a reliable assessment procedure. Indoor air quality tests performed before and after air sealing showed that there was no negative impact on the general conditions of comfort and air quality in the building. The following presents the cost calculations of implementing the air-sealing measure.

Cost of Assessment (Feasibility)

Building inspection, assessment and energy audit:	$ 4,500 (The actual cost was higher because of research element. The stated cost represents a typical assessment cost.)
Infra-red thermography, suite fan tests and air leakage characterization:	$ 2,000 (typical)

Implementation

Air-sealing:	$38,000 (actual)
Inspection and quality control:	$ 1,800 (typical)
Total Cost of Air-Sealing Measure	**$46,300.**

Reductions in Energy Consumption Costs

Monitored results showed the following energy savings:

Reduction in annual energy consumption:	80,370 kWh (@ 4.8% of total electric consumption)
Reduction in monthly peak demand:	42 kW during the months of December and January, and of at least 25 kW in the months of November, February, March and April.

Energy cost reductions at 1990 rate:	80370 kWh x $0.07/kWh = $5,625.
Demand cost reductions at 1990 rate:	42 kW x 2 months x $9.10/kW + 25 x 4 x 9.10 = $1,675.

Total reduction in billing due to air-sealing is $7,300 which is approximately 7.9% of the total 1990 electric bill for the building.

Simple Payback Analysis

The simple payback of the air-sealing measures to the building owner, without considering any financial incentives, is 6.4 years ($46300/$7300).

The air sealing work to improve the building envelope qualifies for Ontario Hydro's incentive program. Ontario Hydro generally pays the full cost of the feasibility study. The incentive for the reduction in peak demand during winter months is calculated as up to $500/kW or 50% of air sealing costs, whichever is less.

The building owner's financial commitment will be as follows:

Feasibility study:			$6500
	Ontario Hydro	-	$6500
	Building Owner		$ 0
Air sealing, inspection and quality control:			$39,800
	Ontario Hydro	-	$19,900 (50% of total cost)
	Building Owner		$19,900
Total costs to the building owner:			**$19,900**

Based on energy savings, the simple payback period is 2.7 years ($19900/$7300).

Other Points

The above analysis does not account for energy savings in the make-up air system which is heated by natural gas. It should be noted that the above analysis presents the cost calculations based on 1990 electricity rates. The 1991 rates are approximately seven percent higher, and the 1992 rates are expected to increase more than 10%. It is our belief that the unit cost of air sealing may remain same for a year or two due to competition and market forces. Cost-benefit assessment should consider these situations.

APPENDIX D: AIRTIGHTNESS TEST REPORT FOR DONALD STREET BUILDING

National Research Council Canada
Conseil national de recherches Canada

Institute for Research in Construction
Institut de recherche en construction

CLIENT REPORT

for

Scanada Consultants Limited
463 MacLaren Street
Ottawa, Ontario
K2P 0M8

Whole-Building Air Leakage Tests on an Ottawa Building

Author

R.J. Magee
Technical Officer

Approved

S.A. Barakat
Head, Building Performance

Report No. CR6346.1
Report Date: 4 April, 1991
Contract No. CR6346
Reference: Application for test dated 16 October, 1990
Section: Building Performance

Pages 7
Copy No. 1 of 5 Copies

Canada

ABSTRACT

This project was undertaken at the request of Scanada Consultants Limited. The objective was to determine the whole-building leakage of a 22-storey apartment building (251 Donald Street, Ottawa) prior to, and immediately after measures were taken to seal the envelope.

TEST BUILDING

The masonry building is 22 stories high. The ground floor has lobby, maintenance, laundry and recreation areas in addition to the apartment of the building superintendent. Twenty stories (2 through 12, 14 through 22: there is no 13th storey) are typical floors, each housing 12 apartment units. The single supply air unit for the building is located in the penthouse.

TEST METHOD

The general procedure for conducting whole-building leakage tests has been described in the Institute for Research in Construction report to Canada Mortgage and Housing Corporation entitled "Establishing the Protocols for Measuring Air Leakage and Air Flow Patterns in High-Rise Apartment Buildings" (Report No. CR5855.1; 18 April, 1990). Specific details of the test conducted at 251 Donald Street are reported below.

Installation of Fan and Flow Monitoring Equipment

A large vane-axial fan with a maximum capacity 23,600 L/s was used to depressurize the building. The fan inlet was connected by 12 m of 0.9 m - diameter ducting to a plywood panel temporarily installed in the double doors adjacent to the garbage room on the west side of the building. The door panel and all joints in the duct/fan assembly were sealed with tape prior to testing. Airflow rates were measured upstream of the fan intake using a pair of total pressure averaging tubes. Flow rates are accurate to within 5% of the measured values.

Installation of Pressure Monitoring Equipment

The pressure differences across the building envelope at both the ground and roof levels were measured using electronic manometers with a strip chart recorder (accurate to within 5% of the measured values). The average of the two measured values was used to represent the mean pressure difference across the building envelope. For measuring exterior pressure at the ground level, clear vinyl tubing (3.2 mm ID) was run to the centre of each of the four exterior walls. The end of each tube was positioned about 1 m above ground level, with the open end pointing downward. Each of the four 50 m long tubes were connected to a single manifold (12.5 x 5.5 cm dia. copper cylinder). The average external pressure at ground level was measured from this manifold. The ground floor interior pressure tap was located at the centre of the ground floor sitting area (South of the main lobby area). To measure the external pressure at the roof, a static pressure probe was placed on the roof adjacent to the South wall of the elevator room. An internal pressure tap was located at the centre of the 22nd floor corridor.

Building Preparation

All exterior windows and doors were shut tightly and continuously monitored during the test. Entrance doors from the corridor into the apartments were blocked to give an opening of approximately one inch. All stairwell doors were blocked fully open. One of the double glass doors (the west one) leading to the ground floor sitting area was blocked wide open, the other door remained closed during the test. Access through the main entrance door was controlled during the test such that the doors remained closed while measurements were in progress. The supply air system and garbage exhaust fan were shut down. Power to the washing machine and dryers was turned off. The following grilles were sealed with plastic sheeting and aluminum tape:

- supply fan intake (roof-top)

- garbage chute vent (roof-top)

- Ground Floor:

  - West Wall: grille 1.8 m South of North end
  - West Wall: grille 7.9 m South of North end
  - West Wall: grille 11.1 m South of North end
  - West Wall: grille 17.2 m North of South end
  - West Wall: grille 8.0 m North of South end
  - West Wall: grille 1.6 m North of South end
  - South Wall: grille 5.2 m West of East end
  - East Wall: grille 5.2 m South of North end

Air Leakage Rate Measurement

Once the building preparation was complete, the duct intake was blocked with a plywood panel. While access to the building was restricted, base readings of the pressure differences across the building envelope were recorded. The block was then removed, the fan was turned on and the flow rate adjusted to give a pressure difference across the building envelope at ground level of approximately 50 Pa. Access to the building was again restricted while pressure differences across the envelope were recorded for a period of 2-3 minutes. The fan flow rate was then adjusted and the procedure repeated for pressure differences of approximately 65, 40, 30 and 20 Pa. The fan was then turned off, the duct intake blocked, and base readings were repeated as described above. To minimize weather effects (wind and stack action), the average of the initial and final base readings were subtracted from the measured envelope pressure differences.

TEST RESULTS

Two test were conducted: Test 1 was conducted on Oct. 23, 1990 prior to the building retrofit, and Test 2 on Mar. 25, 1991 shortly after retrofit completion.

Pressure data and leakage rates for Tests 1 and 2 are given in Tables 1 and 2, respectively. Weather conditions at test time are summarized in Table 3. In Figure 1, the leakage rates vs. the mean pressure difference across the envelope (average of corrected ground and roof level ΔP's) are plotted for both tests.

Table 1: Observations for test date 90-10-23.

Test No.	Test Time	Duct Velocity Pressure (Pa)	Air Flow Rate (L/s)	Observed Pressure Difference, Pa: Grd.Ext. vs. Grd.Int.	Observed: Roof vs. 22nd Cor.	Observed: Mean	Corrected Pressure Difference, Pa (*): Grd.Ext. vs. Grd.Int.	Corrected: Roof vs. 22nd Cor.	Corrected: Mean
In'l Base	15:15	0.0	0	16.6	-22.8				
1	15:25	150.0	10,219	50.1	-2.2	24.0	33.8	20.0	26.9
2	15:34	79.0	7,416	37.5	-6.8	15.4	21.2	15.4	18.3
3	15:44	39.0	5,211	28.8	-16.0	6.4	12.5	6.2	9.3
4	15:55	6.0	2,044	20.0	-18.0	1.0	3.6	4.2	3.9
5	16:07	221.0	12,404	62.4	-2.0	30.2	46.1	20.2	33.1
Final Base	16:25	0.0	0	16.1	-21.5				

* Corrected Pressure Difference = Observed Pressure Difference - Averaged Base Pressure Difference

Table 2: Observations for test date 91-03-25.

Test No.	Test Time	Duct Velocity Pressure (Pa)	Air Flow Rate (L/s)	Observed Pressure Difference, Pa: Grd.Ext. vs. Grd.Int.	22nd Cor. vs. Grd.Int.	Roof vs. Grd.Int.	Roof vs. 22nd Cor.	Corrected Pressure Difference, Pa (*): Grd.Ext. vs. Grd.Int.	22nd Cor. vs. Grd.Int.	Roof vs. Grd.Int.	Roof vs. 22nd Cor.	Ground & Roof Mean
In'l Base	14:40	0.0	0	26.3	-2.9	-21.7	-21.3					
1	14:50	64.0	6,675	51.5	7.5	3.2	-5.5	25.7	10.9	26.1	15.9	20.8
2	14:54	88.2	7,836	57.6	9.6	8.0	-2.5	31.8	13.0	30.9	18.9	25.3
3	14:58	123.0	9,254	65.1	13.4	14.7	0.6	39.2	16.8	37.6	22.0	30.6
4	15:02	141.0	9,908	69.9	15.7	19.1	3.5	44.1	19.1	42.0	24.9	34.5
5	15:07	37.6	5,116	43.9	3.1	-6.2	-10.0	18.1	6.5	16.7	11.4	14.7
6	15:11	18.8	3,618	38.3	0.8	-11.7	-13.8	12.4	4.2	11.2	7.6	10.0
7	15:14	9.8	2,612	35.3	-0.2	-14.5	-15.5	9.4	3.2	8.4	5.9	7.7
Final Base	15:17	0.0	0	25.4	-3.9	-24.0	-21.5					

* Corrected Pressure Difference = Observed Pressure Difference - Averaged Base Pressure Difference

Table 3: Weather conditions during testing.

Weather Parameter	Test No. 1 Oct.23, 1990	Test No. 2 Mar.25, 1991
Outdoor Temperature, C:	8.0	2.5
Indoor Temperature, C:	22.0	23.3
Wind Speed, km/h:	18.5	calm
Wind Direction:	NE	N/A

APPENDIX E: MAKE-UP AIR BALANCING AND TUNING AFTER AIR SEALING

SUNDERLAND AIR BALANCING LTD.

Air Balancing and Related Maintenance Services
Balancement D'Air et Services D'Entretien
9 ETTRICK CRESCENT, NEPEAN, ONTARIO K2J 1E9
TELEPHONE 825-3690

FEB. 22/91

MR. K. RUETT,
SCANADA CONSULTANTS LTD.,
435 MACLAREN ST.,
OTTAWA, ONTARIO
K2P 0M8

JOB: OTTAWA CARLETON HOUSING
251 DONALD

SUMMARY:

1. FRESH AIR MOTORIZED DAMPER HAS TO BE REPAIRED. THE MOTOR WILL NOT DRIVE THE DAMPER OPEN. WE HAD TO OPEN IT BY HAND.

2. THE DESIGN CFM REQUIRED OF 12,200 CFM. OBTAINED FROM THE INDIVIDUAL SUPPLY AIR OPENING IS ONLY 10,405. THIS SYSTEM IS LOW ON SUPPLY AIR BY 1795 CFM OR 15%.

3. THIS SYSTEM CAN BE INCREASED IN THE OUTPUT OF AIR BY INSTALLING NEW DRIVES AND V-BELTS TO REACH 12,200 CFM WITH THE EXSISTING ELECTRIC MOTOR WHICH IS OPERATING THE SUPPLY FAN NOW.

SUNDERLAND AIR BALANCING LTD.

Air Balancing and Related Maintenance Services
Balancement D'Air et Services D'Entretien
9 ETTRICK CRESCENT, NEPEAN, ONTARIO K2J 1E9
TELEPHONE 825-3690

VENTILATION TEST REPORT
RAPPORT - CALIBRATION DE LES VENTILATION

TEST BY / ESSAI PAR: P. SUNDERLAND

DATE / DATE: FEB 20/91

JOB NAME / NOM DU PROJET: OTTAWA CARLETON HOUSING

ADDRESS / ADRESSE: 251 DONALD

SYSTEM / SYSTEME: SUPPLY FAN #1

EQUIPMENT LOCATION / ENDROIT D'EQUIPEMENT: PENTHOUSE MECH. RM.

FAN / VENTILATEUR
- MAKE / MANUFACTURIER: TRANE
- SIZE / GRANDEUR: T17LP-HF-TH
- TYPE / TYPE: CABINET

	RATED / DESIGNE	ACTUAL / ACTUEL
LINE VOLTS / TENSION	575	575
MOTOR AMPS / AMPERAGE MOTEUR	8.6	6.1, 6.0, 6.0

MOTOR / MOTEUR
- HP: 7 1/2
- RPM: 1740

	REQUIRED / REQUIS	ACTUAL / ACTUEL
FAN RPM / VENTILATEUR RPM	—	820
SYSTEM CFM / SYSTEME PCM	12,200	10,405

PULLEY DATA / DONNES POULIE	ADJUSTED TO / ADJUSTE A		
	TOP / HAUTE	MIDDLE / MOIENNE	BOTT / BASSE
MOTOR / MOTEUR	ADJ		
FAN / VENTILATEUR	FIX		

BELTS / COURROIES	NO.	SEC.	SIZE / GRANDEUR
	2	B	68

AREA SERVED / ZONE DESERVIE	OPENING / OUVERTURE NO. / QUATUT.	OPENING / OUVERTURE SIZE / GRANDEUR	FACTEUR K / FACTOR	REQUIRED / REQUIS VEL / VITESSE	REQUIRED / REQUIS CFM / PCM	PRELIMINARY / PRELIMINAIRE VEL / VITESSE	PRELIMINARY / PRELIMINAIRE CFM / PCM	PRELIMINARY / PRELIMINAIRE VEL / VITESSE	PRELIMINARY / PRELIMINAIRE CFM / PCM	FINAL / FINAL VEL / VITESSE	FINAL / FINAL CFM / PCM
22 ND FLOOR	1	16/12	.82	731	600	250	205	609	500	609	500
21 ST FLOOR	2	16/12	.82	731	600	292	240	621	510	621	510
20 TH FLOOR	3	16/12	.82	731	600	402	330	634	520	634	520
19 TH FLOOR	4	16/12	.82	731	600	548	450	646	530	646	530
18 TH FLOOR	5	16/12	.82	731	600	719	590	634	520	634	520

SUNDERLAND AIR BALANCING LTD.

Air Balancing and Related Maintenance Services
Balancement D'Air et Services D'Entretien
9 ETTRICK CRESCENT, NEPEAN, ONTARIO K2J 1E9
TELEPHONE 825-3690

VENTILATION TEST REPORT CONT'D
RAPPORT - CALIBRATION DE LES VENTILATION CONT'D.

JOB NAME / NOM DU PROJET: 251 Donald

SYSTEM / SYSTEME: Supply Fan #1

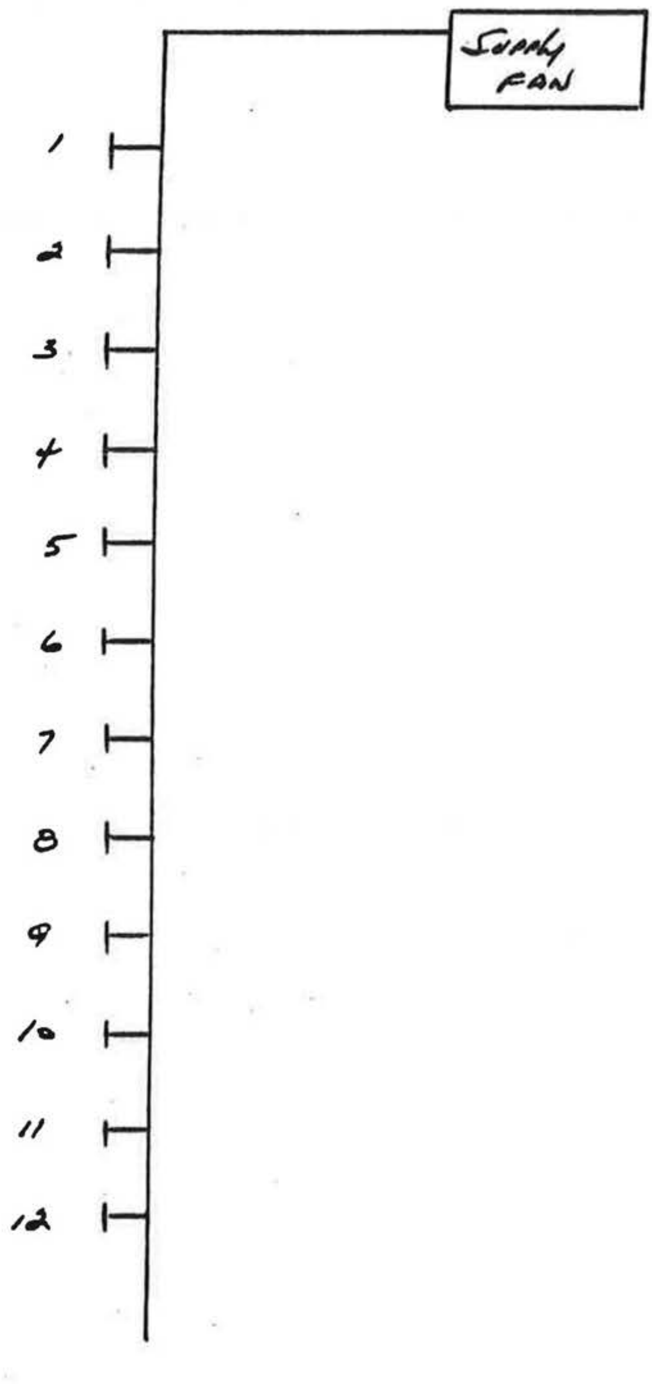
Pg 2-4

AREA SERVED ZONE DESERVE	OPENING OUVERTURE NO. QUATUT.	OPENING OUVERTURE SIZE GRANDEUR	FACTEUR K FACTOR	REQUIRED REQUIS VEL VITESSE	REQUIRED REQUIS CFM PCM	PRELIMINARY PRELIMINAIRE VEL VITESSE	PRELIMINARY PRELIMINAIRE CFM PCM	PRELIMINARY PRELIMINAIRE VEL VITESSE	PRELIMINARY PRELIMINAIRE CFM PCM	FINAL FINAL VEL VITESSE	FINAL FINAL CFM PCM
17 TH Floor	6	16/12	.82	731	600	329	270	621	510	621	510
16 TH Floor	7	16/12	.82	731	600	853	700	634	520	634	520
15 TH Floor	8	16/12	.82	731	600	609	500	609	500	609	500
14 TH Floor	9	16/12	.82	731	600	304	250	609	500	609	500
12 TH Floor	10	16/12	.82	731	600	597	490	621	510	621	510
11 TH Floor	11	16/12	.82	731	600	500	410	621	510	621	510
10 TH Floor	12	16/12	.82	731	600	432	355	634	520	634	520
9 TH Floor	13	16/12	.82	731	600	548	450	634	520	634	520
8 TH Floor	14	16/12	.82	731	600	597	490	628	515	628	515
7 TH Floor	15	16/12	.82	731	600	469	385	609	500	609	500
6 TH Floor	16	16/12	.82	731	600	548	450	634	520	634	520
5 TH Floor	17	16/12	.82	731	600	439	360	597	490	597	490
4 TH Floor	18	16/12.	.82	731	600	384	315	609	500	609	500
3 RD Floor	19	16/12	.82	731	600	878	720	609	500	609	500
2 ND Floor	20	16/12	.82	731	600	445	365	621	510	621	510
1 ST Floor	21	12/6	.37	540	200	932	345	540	200	540	200

SUNDERLAND AIR BALANCING LTD.

Air Balancing and Related Maintenance Services
Balancement D'Air et Services D'Entretien
9 ETTRICK CRESCENT, NEPEAN, ONTARIO K2J 1E9
TELEPHONE 825-3690

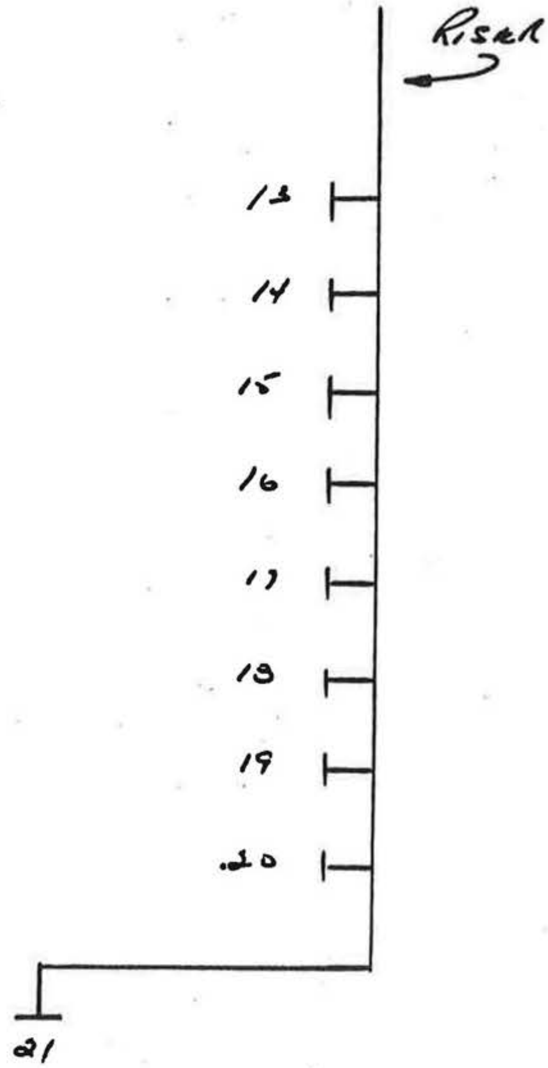
SUPPLY FAN #1 FEB 20/91 PG - 3-4



SUNDERLAND AIR BALANCING LTD.

Air Balancing and Related Maintenance Services
Balancement D'Air et Services D'Entretien
9 ETTRICK CRESCENT, NEPEAN, ONTARIO K2J 1E9
TELEPHONE 825-3690

Supply FAN #1 FEB 20/91 PG- 4-4



METRICAIR INCORPORATED
P.O. BOX 1213, STATION "B", MISSISSAUGA, ONTARIO L4Y 3W5 TEL. (416) 566-980

AIR BALANCING REPORT

PROJECT: 2500 Brideltown Circle
Condominium Apartment
Scarborough, Ontario

CONTRACTOR:

ENGINEER: Scanada Consultants Limited

Air Balancing methods and applications used to compile a final Balancing Report:

Instruments used:

1. Combination Inclined-Vertical Manometers
2. Differential Pressure Gauges
3. Magnehelic Gauges
4. Pitot Tubes (various lengths)
5. Alnor Velometers and probes
6. Rotating Van Anemometers
7. Clamp on Amprobes
8. Automatic Type Tachometers
9. Sling Psychrometers
10. Insertion Thermometers (wb & db)

(1) All fans and air handling equipments are tested and set up as per manufacturers' shop drawings. All main and branch ducts are measured and set to required C.F.M. by means of pitot tube traverses.

Systems will be balanced so that fans operate at the lowest static pressure possible.

(2) On all supply diffusers velocity readings will be taken with an Alnor Velometer using the correct factors of effective areas. Perforated type diffusers will be measured with measuring hood and Rotating Vane Anemometer.
On all supply return and exhaust grilles and registers a Rotating Vane Anemometer is used with manufacturers' factors of effective areas.

All balancing procedures are in accordance with the Associated Air Balance Council's Standards.

METRICAIR INCORPORATED

FAN SHEET

PROJECT:	2500 Brideltowne Circle
SYSTEM:	FA-1
	Corridor Fresh Air Unit
DATE:	Jun 20/91
Page:	1
Of:	2

AUG 19 '91 10:47 SCHNAUR CONSULTANTS

DESIGN DATA FOR FAN		DESIGN DATA FOR MOTOR	
RATED CFM	6950	MOTOR MAKE	Brooks
TOTAL OUTLET CFM	6950	MOTOR HP	7.5
TOTAL S.P.	N/A	MOTOR VOLTS	416
RATED RPM	N/A	MOTOR PHASE	3
RATED BHP	N/A	MOTOR RPM	1720
ACTUAL CFM	7103	NAME PLATE AMPS	14.0

SCHEMATICS

FIELD TEST DATA

FAN MAKE	HASTINGS				MOTOR RPM		1780	
FAN MODEL	N/A				DIRECT DR			
FAN RPM	570				VOLTAGE:	PHASE 1	416	
SUCTION S.P.	0.200"					PHASE 2	416	
DISCHARGE	0.550"					PHASE 3	416	
TOTAL S.P.	0.750"				AMPS	PHASE 1	8.5	
PULLEYS DATA	FIX	ADJUSTED Max	Med	Min		PHASE 2	9.0	
MOTOR	X					PHASE 3	9.5	
FAN	X				FILTER P.D.	.100"	W.G.	
BELTS	2B72				HEATING COIL P.D.	N/A	W.G.	
TEST CONDITION		100% FA	X☐		COOLING COIL P.D.	N/A	W.G.	
MIN.FA	☐	100% RA	☐					
		100% EA	☐					

REMARKS:

METRICAIR
I[illegible] CORPORATED

AIR BALANCING SHEET

PROJECT: 2500 Brideltowne Circle
[illegible]: FA-1
[illegible]rridor Fresh Air [illegible]t
DATE: Jun 20[illegible] PAGE: 2 OF: 2

ROOM NO.	NAME	DESIGNED DATA NO.	SIZE	CAPACITY CFM	CALCULATED DATA E/A	F.P.M.	V.P.	TESTING DATA No. 1	No. 2	No. 3	No. 4	MEASURED DATA AVG.	F.P.M.	CAPACITY CFM
0[illegible]	Corr[illegible]	1	26 x 26 "G"	695	2.82	246							25[illegible]	716
[illegible]	[illegible]dor	2	26 x 26 "G"	695	2.82	24[illegible]							260	733
	[illegible]dor	3	26 x 26 "G"	695	[illegible]	[illegible]6							270	761
	Corridor	4	26 x 26 "G"	69[illegible]	[illegible]82	[illegible]							260	733
	Corridor	5	26 x 26 "G"	695	2.82	246							245	691
	Corridor	6	26 x 26 [illegible]	695	2.[illegible]	245							240	677
	Corridor	7	26 x 26 "G"	69[illegible]	2.82	24[illegible]							250	705
	Corridor	8	26 x 26 "G"	695	[illegible].82	24[illegible]							245	691
	Corridor	9	26 x 26 "G"	69[illegible]	2.82	246							260	733
G	Corridor	[illegible]	26 x 26 "G"	695	2.82	2[illegible]							[illegible]35	[illegible]83
	TOTAL OUTLET		1-1[illegible]	[illegible]695										7103

REMARKS

E/A = EFFECTIVE AREA SQ. FT. F.P.M. = FEET PER MINUTE [illegible]ITY F[illegible] [illegible]
AVERAGE = SUMMATION OF TRAVERSE READINGS. INCH WG.
D = DIFFUSER G = GRILLE R = REGISTER T = TROFFER
L = LINEAR DIFFUSER PD = PERFORATED DIFFUSER
OP = OPENING (OPEN ENDED DUCT)

AUG 19 [illegible]

APPENDIX F: PRESENTATION OF PROJECT

F-1 Technical Paper

Attached technical paper was presented at 12th Conference of Air Infiltration and Ventilation Centre held in Ottawa during September 22-27, 1991.

F-2 Presentation Material

The overhead slides and photographs were used to make several presentation on this project.

AIR MOVEMENT & VENTILATION CONTROL WITHIN BUILDINGS

12th AIVC Conference, Ottawa, Canada
24-27 September, 1991

Paper No.

Title

COMPARISON OF AIRTIGHTNESS, INDOOR AIR QUALITY AND POWER CONSUMPTION BEFORE AND AFTER AIR-SEALING OF HIGH-RISE RESIDENTIAL BUILDINGS

Author (s)

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Toronto, Ontario M5G 1X6

COMPARISON OF AIRTIGHTNESS, INDOOR AIR QUALITY AND POWER CONSUMPTION BEFORE AND AFTER AIR-SEALING OF HIGH-RISE RESIDENTIAL BUILDINGS

SYNOPSIS

Air infiltration and ventilation has a profound influence on both the internal environment and on the energy needs of buildings. In most electrically heated high-rise residential buildings, in cold climates, during the peak winter conditions (below -18 deg C ambient temperature and above 15 km/hour wind velocity), the air infiltration component contributes to heating load by 10 to 18 W/m^2 - roughly 25 to 35% of peak heating demand. Any reduction in such uncontrolled air infiltration, without sacrificing indoor air quality, will have potential to reduce the peak heating demand. To evaluate the effectiveness of air-sealing measure, the air leakage rates through the building envelope were measured both before and after the air-sealing using the large vane-axial fan. Several air quality measurements (indoor temperatures, relative humidity, CO_2, formaldehyde, radon gas) were taken in each building to assess the practical implications of air sealing on the indoor air quality and thermal comfort.

The whole building airtightness tests showed that the air-sealing of the building envelope reduced the air leakage rate by 32% in one building and 38% in other. Energy monitoring for two buildings showed the reduction in heating demand by approximately 6 W/m^2 of floor space -- 12 to 15% due to air leakage control. Indoor air quality tests showed that the air sealing had no negative impact on the general conditions of comfort and air quality in both buildings. The field implementation of air leakage control has helped to remove some of the uncertainties and shown the potentials for conservation are indeed considerable. This paper presents the field tests and results, and suggest a procedure for the use by air-sealing practitioners to evaluate different air-sealing strategies.

1. INTRODUCTION

Concerned especially with reducing peak power demand, Ontario Hydro (the largest electric utility in Canada) is exploring various energy conservation strategies and their potentials. One way to obtain load reduction and energy efficiency is through improvements in the efficiency of electric space heating in high-rise residential buildings.

The energy audit and assessment of four high-rise residential buildings located in Ontario showed that the peak space heating demand varies from 35 to 65 W/m^2 of floor space. During peak winter conditions, the air leakage component contributes to the heating load by 10 to 18 W/m^2 - roughly 25 to 35% of the peak heating demand [Scanada 1991]. Therefore, the control of air leakage in buildings has become recognized as a key element in achieving energy conservation. Clearly, if high-rise buildings could be better air-sealed, the potentials for reductions in peak demand (plant capacity) and energy usage, and the associated costs, should be enormously attractive to building owners and the utility.

Despite the importance of the process of air leakage in high-rise buildings, it is still an aspect of building science about which there is considerable uncertainty. In part, this problem has been made difficult by the diverse range of buildings, each constructed according to widely varying construction practices. The quantification of air leakage flows is difficult due to the complexities of the flow mechanisms. It is this lack of design considerations in the building construction which has frequently resulted in higher heating consumption, and moisture and air quality problems. Clearly, good predictive design methods and demonstrations of air leakage control should assist in formulating programs relating to improve the energy efficiency of high-rise buildings. This paper describes a procedure to assess air leakage and field tests conducted to assess the effects of air-sealing on overall building airtightness, indoor air quality, and power consumption before and after air-sealing of two high-rise residential buildings.

2. PROCEDURE TO DETERMINE AIR LEAKAGE RATE

A simplified air leakage estimation procedure was developed, based primarily on equivalent air leakage area and local net pressure distribution [Scanada-1 1991]. The pressure difference at a given location depends on the infiltration driving forces (stack, wind and mechanical ventilation) and the characteristics of the opening in the building envelope. A simplified network of air-flow paths can be established using the following information: climate and exposure, building types, building form, building dimensions, surface to volume ratios, shafts, and envelope types, windows and doors, envelope crack lengths, openings, and make-up air strategies. The algebraic sum of air-flow through these paths must always be equal to zero. By applying the mass balance equation, the component of air infiltration which would be occurring during the peak winter condition can be determined. This air-flow rate is responsible for the space heating load due to uncontrolled infiltration. Any reduction in this infiltration flow should decrease the heating requirements for the building. The procedure has been simplified and developed into a practical application tool which will be utilized by assessors and air leakage control contractors.

The leakage paths on the exterior building envelope and shafts are classified as following:

- the basement floor plus ground floor [A_G],
- typical floor [A_T], and
- top floor and penthouse [A_R].

Assuming that there is a neutral zone at the mth floor as shown in Figure 1, the infiltration rate Q_i and exfiltration rate Q_o through the exterior wall can be expressed as the following with the inner/outer pressure differential ΔP (Pa) and leakage area A (m^2):

$$Q_i = A_G\sqrt{(2|\Delta P_G|/\rho)} + \sum_{j=2}^{M-1} A_{Tj}\sqrt{2|\Delta P_j|/\rho)} \quad (1)$$

and

$$Q_o = \sum_{j=M}^{N} A_{Tj}\sqrt{2|\Delta P_j|/\rho)} + A_R\sqrt{(2|\Delta P_R|/\rho)} \quad (2)$$

The airflow balance is

$$Q_i = Q_o \quad (3)$$

where,
- Q = Airflow rate, m^3/s *i* - in-flow, *o* - out-flow
- A = leakage area, m^2
- ρ = air density, kg/m^3
- ΔP = pressure difference across building envelope, Pa

The solution to the above three equations can be obtained using the following steps:

1. Determine the leakage paths at each floor and assign the leakage class (visual inspection, thermography, and simple tests...)
2. Establish the stack pressure, wind pressure and pressure due to mechanical ventilation and determine the net indoor/outdoor pressure difference (ΔP) at each floor.
3. Calculate the air flows at each floor level using the above equations by assuming first that the neutral pressure plane (NPP) occurs at the mid height of the building.
4. Equate the air inflow and outflow ($Q_i = Q_o$). If inflow is greater than outflow, then move the NPP one floor below and repeat the calculations as in Step 3. If the inflow

is lower than the outflow, then assume the NPP one floor above and repeat the calculations. These steps should be repeated until at least three percent difference between inflow (Q_i) and outflow (Q_o) is obtained.

5. The air inflow (Q_i) to the building is the uncontrolled air infiltration. Reduction in this component will result in reducing the peak heating demand and energy consumption.

Based on the above method of determining air leakage rate, a field inspection procedure was developed to assess the potential reductions in peak heating demand [Scanada-2 1991]. The air leakage assessment procedure addresses four concerns: (1) What is the air leakage in the building? (2) How much reduction in peak demand is possible with air leakage control? (3) What will be the air sealing priorities and effectiveness for achieving maximum ratio of reduction in kW to the air sealing costs? and (4) How tight can buildings be and still supply adequate ventilation and maintain indoor air quality? Figure 5 shows the algorithm of the assessment procedure.

3. FIELD DEMONSTRATION AND RESULTS

Two buildings were selected for the demonstration of air leakage control. The following tests were conducted to characterize these buildings before and after the air-sealing work: (i) visual inspection and assessment of air leakage paths, (ii) whole building airtightness tests, (iii) indoor air quality, and (iv) monitoring of energy and power consumption. The buildings are as follows:

Building A: It is a fairly well maintained 21-storey apartment tower located in Ottawa in an open and flat terrain. Its 240 suites are fully occupied. The total heated floor space is 14,290 m^2 and the heated volume is 43,515 m^3. The exposed building envelope area is 7,470 m^2. A detailed energy audit of the building showed that the average annual space heating energy consumption was 105 kWh/m^2/year. The peak space heating demand during the winter months was 42 W/m^2. Ottawa has 4,634 heating degree days and the winter design temperature of -23 °C and wind speed of 12.5 m/s.

Building B: It is a ten-storey apartment building located in a suburban of Toronto. Its 95 suites are fully occupied. The total heated floor space is 9,825 m^2 and volume is 25,455 m^3. A detailed energy audit showed that the average annual space heating energy consumption was 98.6 kWh/m^2/year. The peak space heating demand during the winter months was 46 W/m^2. Toronto has 3646 heating degree days and the winter design temperature is -18 °C and wind speed of 11.5 m/s.

3.1 Estimation of Potential for Air Leakage Control

The air leakage assessment procedure was used to determine the potential for air leakage control in these buildings. The field inspection showed that the total leakage area in the Building A was 2.72 m^2. The air leakage rate at the peak winter conditions was calculated using the above Equations 1, 2 and 3. Figure 2 shows the air leakage rates at the peak winter design condition. The air leakage rate in Building A was 5,990 L/s, resulting in a heating demand of 265 kW - approximately 42% of peak space heating load. By assuming that the air sealing can reduce the uncontrolled air leakage by 32%, the resulting in peak heating demand would be approximately 92 kW. Similar approach was used to assess the Building B. The air leakage control could potentially reduce the peak demand by approximately 33 kW in the Building B.

3.2 Airtightness Tests

A test procedure "*Establishing the Protocols for Measuring Air Leakage and Air Flow Patterns in High-Rise Apartment Buildings*" was used to conduct the whole airtightness tests in both buildings [Magee and Shaw 1990].

Building A: A large axial vane fan with maximum capacity of 23,600 L/s was used to depressurize the building. The fan inlet was connected by 12 m of 0.9 m diameter ducting to a plywood panel temporarily installed in the double doors. Airflow rates were measured upstream of the fan intake using a pair of total averaging tubes. Flow rates are accurate within 5% of the measured values. As shown in Figure 3, this building had a net uncontrolled air leakage rate of 4,740 L/s at 10 Pa pressure difference before air-sealing retrofit. The second test conducted after the air-sealing retrofit showed that the air leakage rate reduced to 3,220 L/s at 10 Pa pressure difference. As shown in Figure 4, the improvement in airtightness was 32% after air-sealing.

Building B: The airtightness results showed that the air leakage rate was 1,885 L/s at 7 Pa pressure difference before air-sealing retrofit. The air-sealing of the building envelope reduced the air leakage rate to 1,165 L/s at 7 Pa pressure difference. The improvement in airtightness was 38% after the air-sealing.

3.3 Indoor Air Quality

Air quality in residential buildings is an area of great concern. With the trend to conserve energy, the effects on air quality should be evaluated to avoid potential health problems which may result from the drastic reduction in air change. Therefore, during this study, air quality tests to monitor the effects of air sealing work were done before and after the air sealing using a test protocol developed by CMHC [CMHC 1990]. The following air quality indicators were chosen for these buildings: formaldehyde, radon, carbon dioxide, relative humidity and indoor temperature. In the Building B, carbon monoxide samples were taken at the ground and underground parking level.

Formaldehyde: The formaldehyde readings did increase slightly in some apartments while remained relatively same in other apartments. However, the upper levels of formaldehyde concentration were well below acceptable limit of 0.1 ppm for residential occupancies.

Radon: Radon samples were taken at the basement, ground and first floor levels. There was not any significant change in the radon level after the air sealing retrofit. The maximum level recorded in these buildings was 20 Bq/m^3 (0.54 pCi/L) which is well below the acceptable level of 148 Bq/m^3 (4 pCi/L).

Carbon Dioxide: The carbon dioxide levels either remained the same or increased in some apartments after the air sealing. However, the upper levels of CO_2 were less than 1000 ppm.

Relative Humidity: The relative humidity levels increased in the lower floor apartments and decreased in the upper storeys. The average RH was at 29% before and 32% after air sealing. The measured data RH readings were within the human comfort zone.

Carbon Monoxide: CO samples were taken at the underground parking and ground floor level at the Building B. Comparison of samples showed no significant difference. The CO levels were well below the accepted limit of 11 ppm.

In both these buildings, it was also observed that the air sealing had reduced the movement of stale odours. In fact, the sealing allowed for more consistent adjustment of air supply to the apartments. The air sealing had no negative impact on the general indoor air quality in the test buildings. Variations and divergent trends observed from apartment to apartment were quite representative of what could be expected due to occupants' lifestyle and habits.

3.4 Comparison of Energy Consumption Before and After Air Sealing

Energy consumption in both the buildings was continuously monitored at every 15 minute interval. The total electric supply to the building and the hot water loads were monitored from the month of November 1990 to June 1991. Similar weather periods, before and after air sealing, were selected to compare the energy consumption. The analysis was performed using the hourly energy simulation program to develop appropriate correction factors to account for solar gains, weather effects and occupancy using the building description. The results are summarized as follows:

Building A: The comparison of similar weather periods showed that the difference in electric load before and after air-sealing was 64 to 84 kW depending on the ambient conditions. Using the building characteristics, and an assumed weather profile for a peak day (ambient temperature varying from -18 to -21 °C and average wind speed of 12.5 m/s) simulation was performed to predict the potential reductions in heating load. Results showed that the reduction in heating load due to air-sealing would be 85 kW on a peak day -- a reduction of 14% of the peak space heating demand. The space heating energy consumption during the heating season reduced by 12%.

Building B: The comparison of similar weather periods showed that the difference in electric load before and after air-sealing was 24 to 35 kW depending on the ambient conditions. Analyses using the building characteristics and an assumed weather profile for a peak day (ambient temperature varying from -15 to -18 °C and average wind speed of 11.5 m/s) were performed to predict the potential reductions in heating load. The reduction in heating load due to air-sealing was 38 kW on a peak day -- an 18% of the peak space heating demand. This reduction in space heating load represents 10.5% of the total electric load for the building. The energy consumption during the heating season reduced by 15%.

4. CONCLUSIONS

- Based on the successful demonstration of air-sealing work and the use of assessment procedure, it can be concluded that the air leakage control offers a potential to reduce the peak electric demand by 4 to 10 W/m^2 of floor space depending on the location and building characteristics.

- A method has been developed to determine the air leakage rate for high-rise buildings. This assessment procedure has been validated with the field demonstration of air leakage control in two high-rise buildings.

- Indoor air quality tests showed that the air sealing of the building had no negative impact on the general conditions of comfort and air quality in both buildings. In both these buildings, it was also observed that the air sealing had reduced the movement of stale odours. In fact, the sealing allowed for more consistent adjustment of air supply to the apartments.

REFERENCES

1. CMHC 1990: "*Indoor Air Quality Test Protocol for Highrise Residential Buildings*", Canada Mortgage and Housing Corporation, Ottawa, Ontario.
2. Magee R.J. and Shaw C.Y. 1990: "*Establishing the Protocols for Measuring Air Leakage and Air Flow Patterns in High-Rise Apartment Buildings*", Report prepared for Canada Mortgage and Housing Corporation, Ottawa, Ontario.
3. Scanada-1 1991: "*Development of Design Procedures and Guidelines for Reducing Electric Demand by Air Leakage Control in High-Rise Residential Buildings*", Scanada Consultants Limited. Report prepared for Ontario Hydro, Toronto, Ontario.
4. Scanada-2 1991: "*Multi-Storey Residential Buildings Weatherization Project - High-Rise Residential Weatherization: Procedure for Assessing Air Leakage and Potential Control in Electrically Heated Residential Buildings of Eight Storeys and Higher*", Scanada Consultants Limited. Report Prepared for Ontario Hydro, Toronto, Ontario.

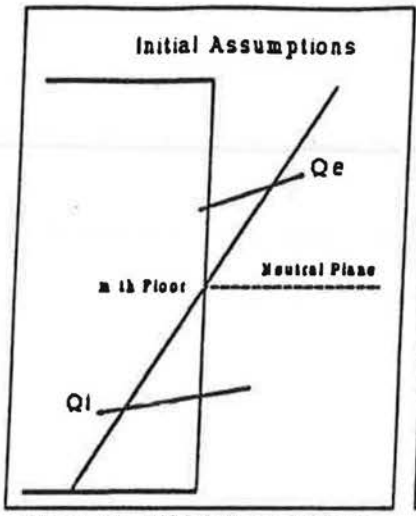


Figure 1: Initial Assumptions.

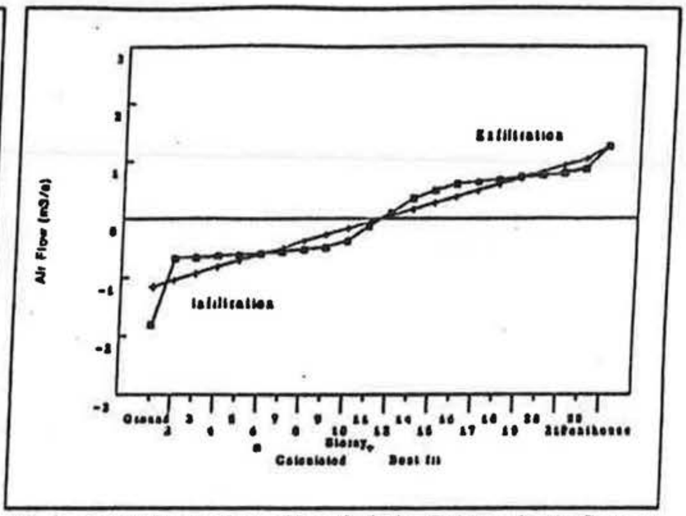


Figure 2: Estimated profile of air in-flow and out-flow at the peak winter conditions for the Building A.

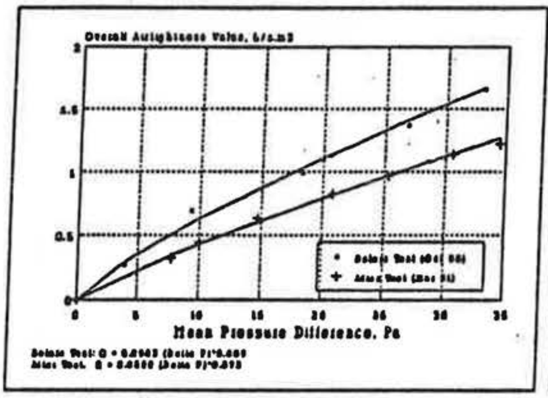


Figure 3: Effect of air-sealing on airtightness of Building A.

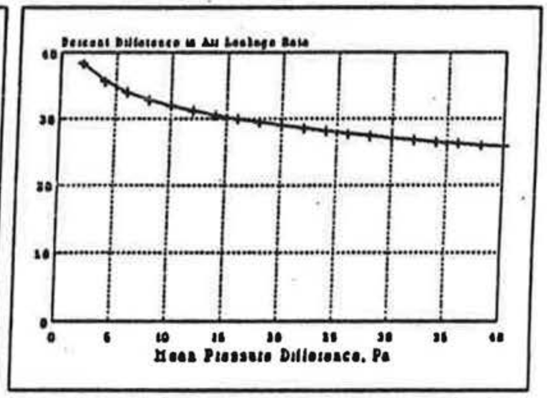


Figure 4: Difference in air leakage rate before and after air sealing of Building A.

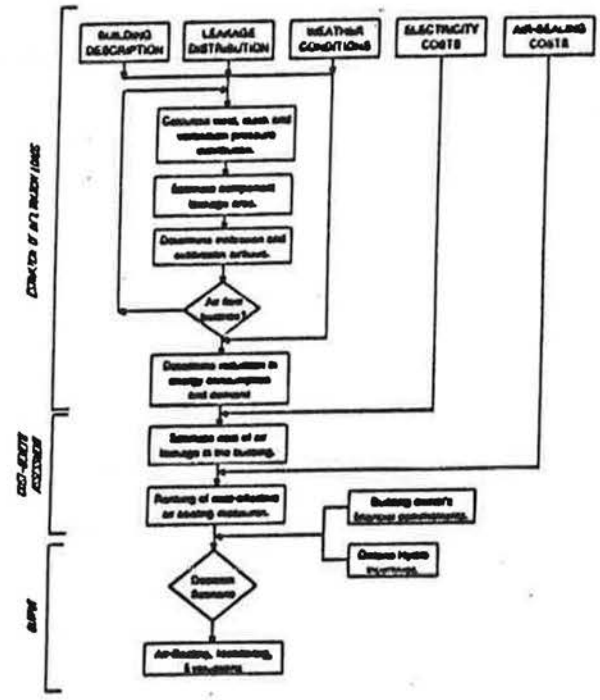


Figure 5: Procedure for Assessing Air Leakage and Potential Control in Electrically Heated Residential Buildings of Eight Storeys and Higher.

Power and Energy Savings from Air Sealing Multi-Residential Buildings

Prepared for

Ontario Hydro

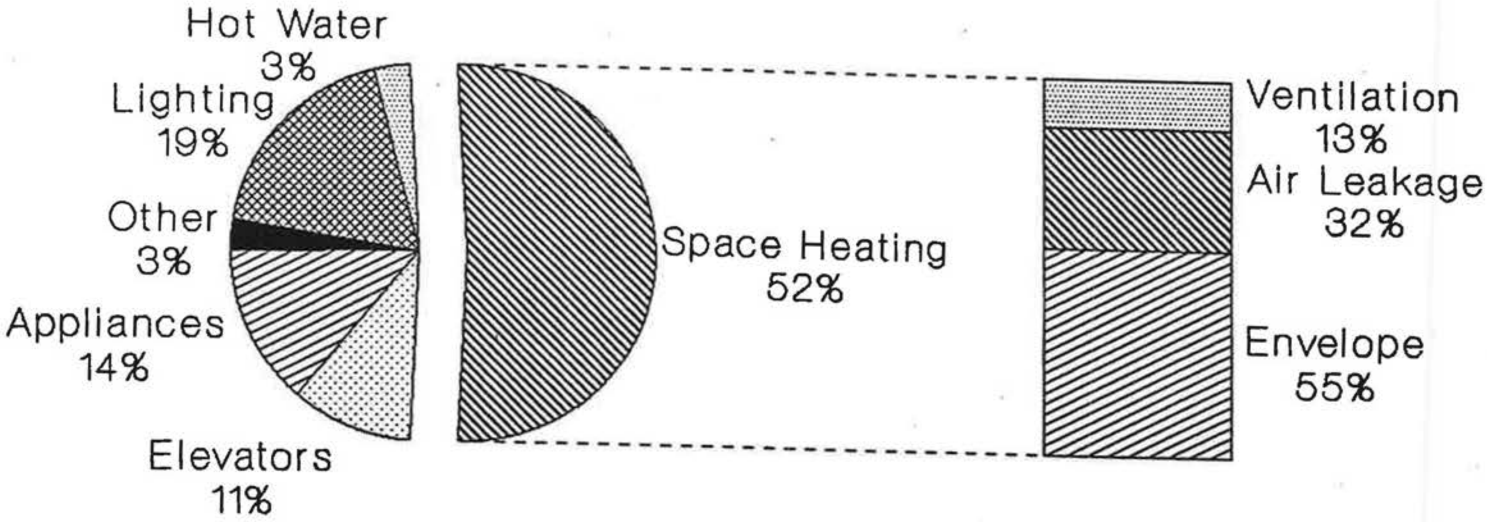
Canada Mortgage and Housing Corporation

Scanada Consultants Limited

CanAm Building Envelope Specialists Inc.

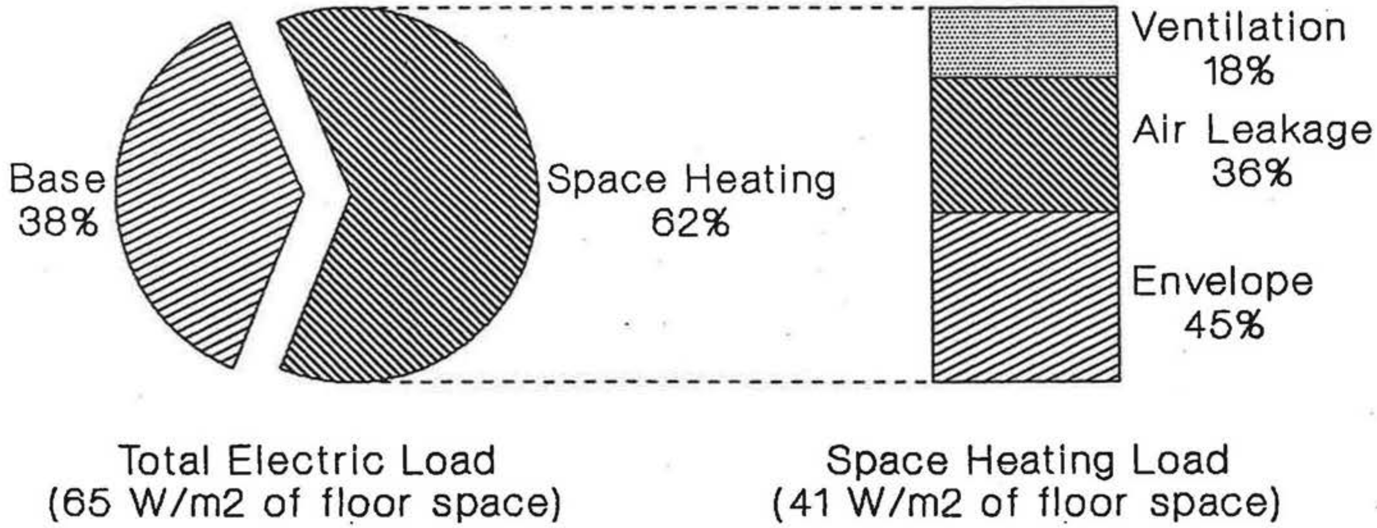
July 1991

Average Annual Energy Use in Four High-Rise Residential Buildings
(215 kWh/year/m2 of floor space)

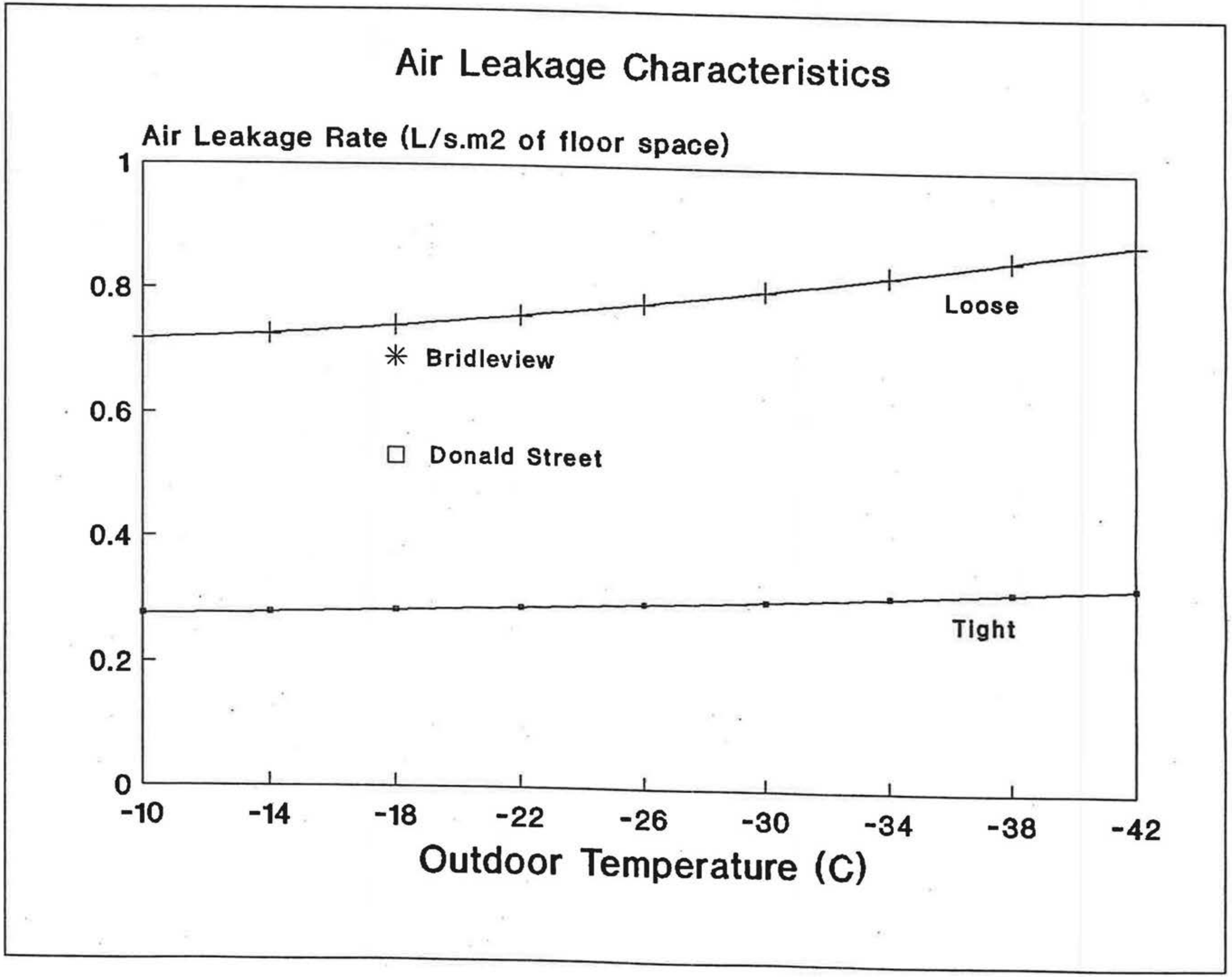


Based on energy audit of four buildings.

Peak Electric Consumption in High-Rise Residential Buildings



Based on energy audit of four buildings.



Air Leakage Characteristics
Air Leakage Rate (L/s.m2 of floor space)
1
0.8
0.6
0.4
0.2
0
Loose
Bridleview
Donald Street
Tight
-10
-14
-18
-22
-26
-30
-34
-38
-42
Outdoor Temperature (C)

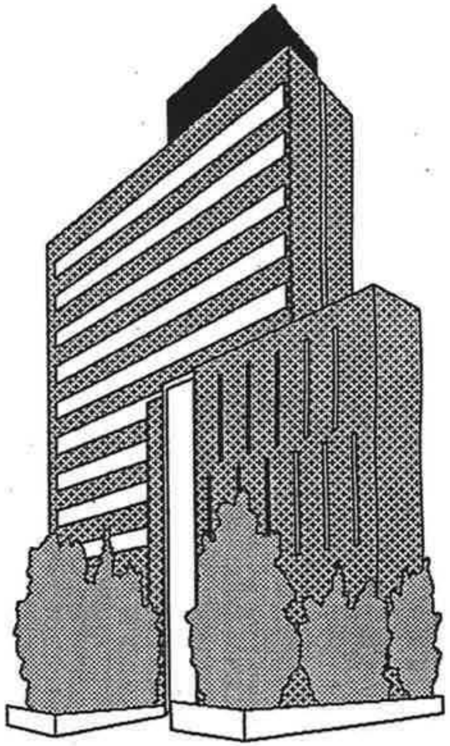
Objectives

- to develop practical design procedures for estimating reductions in peak power demand and energy consumption by air leakage control of high-rise residential buildings; and
- to test airtightness of two buildings, verify the assessment procedure and to show the potential reduction in peak power and energy consumption due to air-sealing.

Approach

- Develop a thermal model for assessing air leakage in high-rise buildings
- Field implementation and validation
  - Assessment of air leakage and potential energy savings
  - Perform the following "before" and "after" tests
    - Building airtightness tests
    - Indoor air quality tests
    - Energy and power monitoring
  - Implement air-sealing - quality control
  - Analyze and evaluate air-sealing implications
  - Compare the predicted and monitored data
  - Modify and fine-tune the assessment procedure
- Develop the air sealing assessment procedure for use by practioners

Procedure for Assessing Air Leakage and Potential Control in Electrically Heated Residential Buildings of Eight Storeys and Higher



Prepared for

Ontario Hydro

Scanada Consultants Limited
CanAm Building Envelope Specialists Inc.

May 1991

H-7

Determination of Air Leakage Rate in High-Rise Buildings

Methods:

- "whole" building airtightness tests

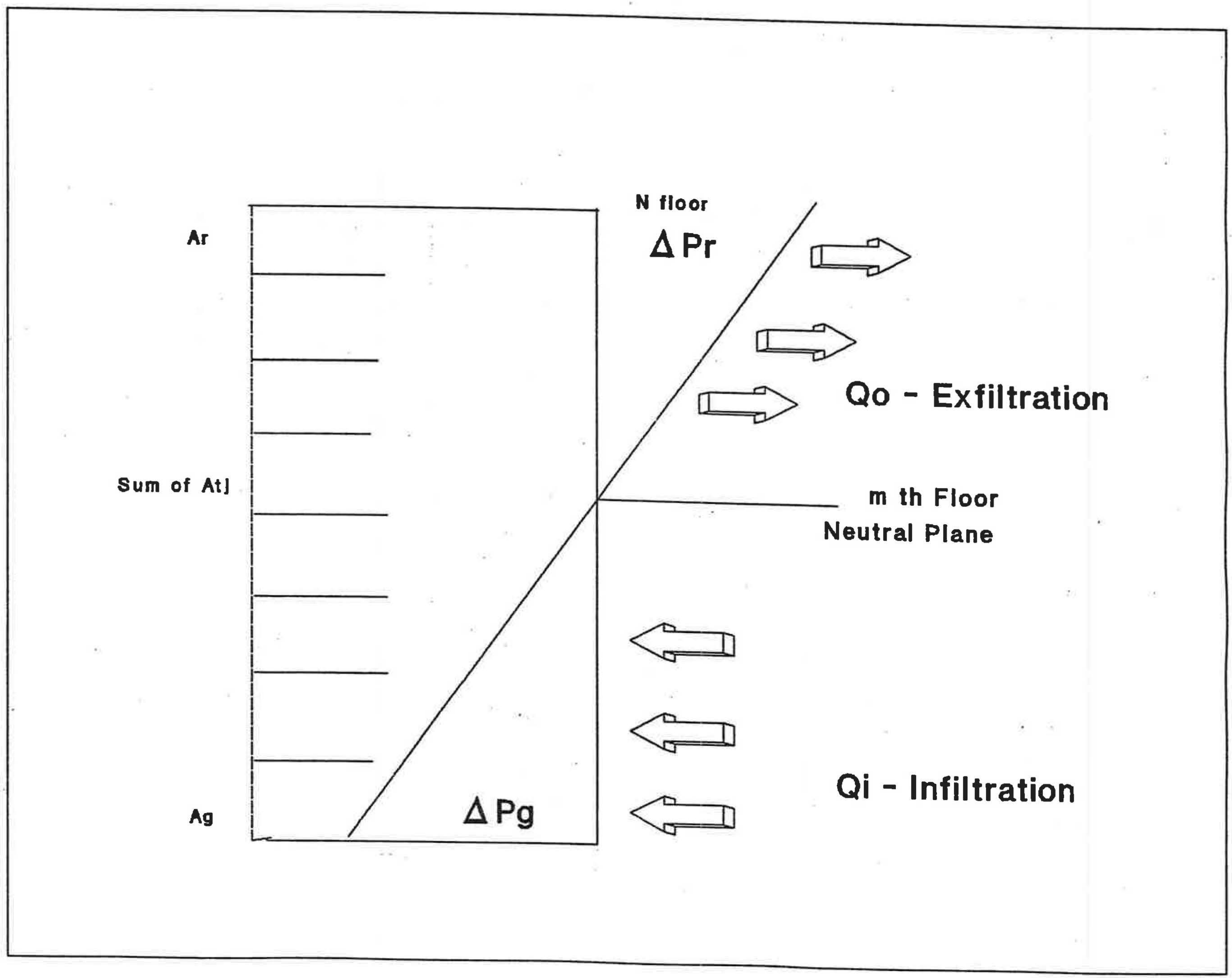
- air-leakage assessment procedure
  - field inspection of leakage paths
  - determination of air leakage rate

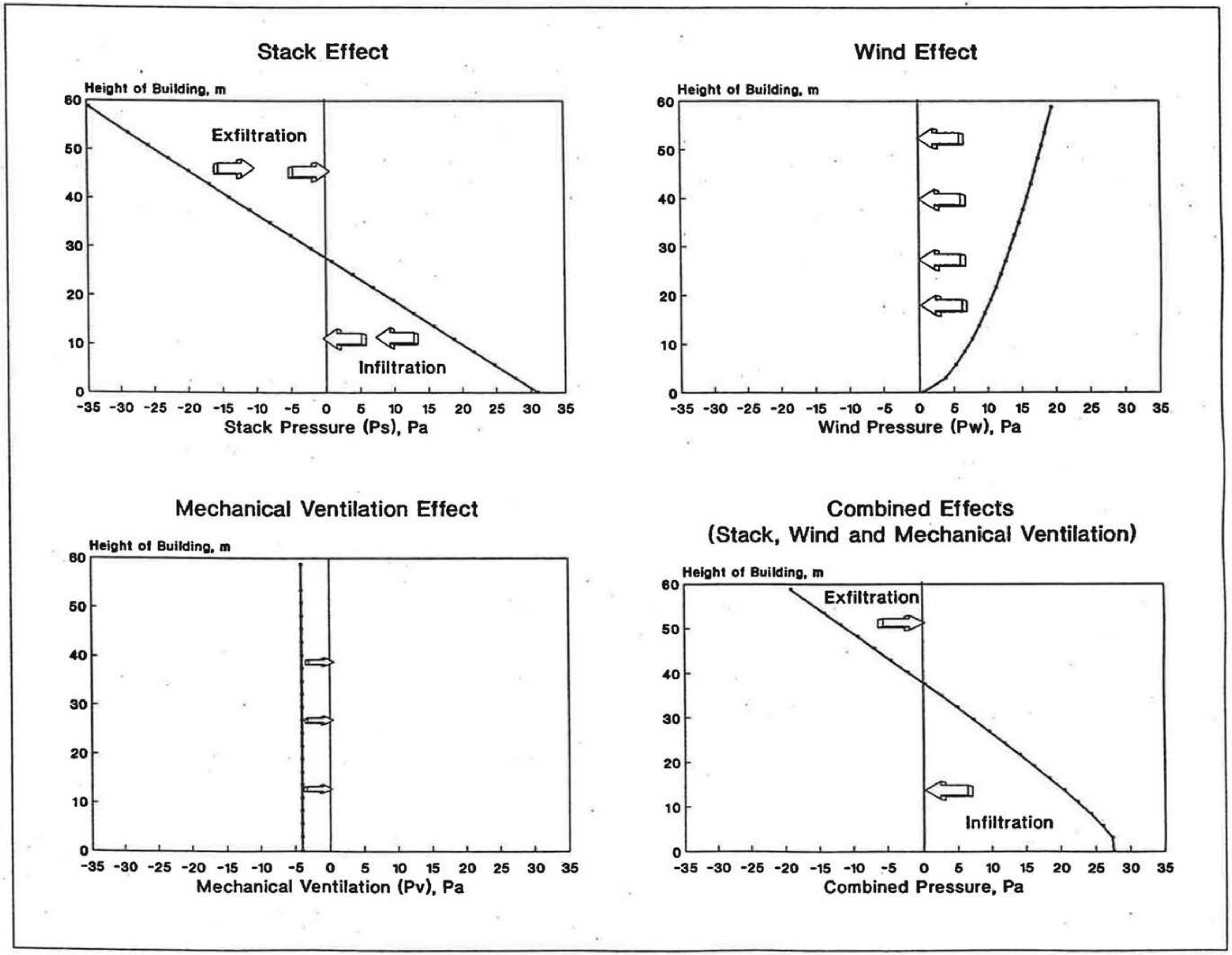
Factors influencing air leakage in high-rise buildings:

- Climate influence
  - outdoor / indoor temperature difference (stack effect)
  - wind effect

- Topographic environment
  - wind shielding
  - terrain
  - surroundings

- Overall airtightness of the building
  - building type, form, dimensions, surface to volume ratio, construction
  - envelope type, windows, doors, envelope crack lengths, openings and make-up air strategies


N floor
ΔPr
Ar
Qo - Exfiltration
Sum of Atj
m th Floor
Neutral Plane
Qi - Infiltration
Ag
ΔPg


Stack Effect
Height of Building, m
Exfiltration
Infiltration
Stack Pressure (Ps), Pa
Wind Effect
Height of Building, m
Wind Pressure (Pw), Pa
Mechanical Ventilation Effect
Height of Building, m
Mechanical Ventilation (Pv), Pa
Combined Effects
(Stack, Wind and Mechanical Ventilation)
Height of Building, m
Exfiltration
Infiltration
Combined Pressure, Pa
0 10 20 30 40 50 60
-35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35

Wind Pressures

$$P_w=(\rho C_p V_H^2)/2$$

where,

P_w	=	surface pressure due to wind, Pa
C_p	=	pressure coefficient
V_H	=	wind speed, m/s

$$V_{ref}=A_o V_{met}$$

$$V_H=V_{ref}(H/H_{ref})^a$$

Coefficient for determining wind velocity, V_{H}

Terrain	A_o	a
Airport (building in a flat terrain)	1.0	0.15
Suburban (cluster of low-rise buildings)	0.60	0.28
Urban (high-rise buildings in populated districts)	0.35	0.40

Averaged Wind Pressure Coefficient, C_p.

Wind Angle (degree)	L/W = 1	L/W = 0.25	L/W = 4
0	0.62	0.62	0.62
10	0.60	0.60	0.60
20	0.58	0.55	0.58
30	0.5	0.40	0.52
40	0.37	0.25	0.45
50	0.25	0	0.37
60	0	-0.25	0.22
70	-0.2	-0.50	0.10
80	-0.37	-0.62	-0.10
90	-0.6	-0.62	-0.25

Stack Pressures

$$P_s = \rho g (h1 - h2)[T_i - T_o]/T_o$$

where,

P_s	=	*pressure difference due to stack effect, Pa*
ρ	=	*air density, kg/m^3 (about 1.2)*
T_i	=	*indoor temperature, K*
T_o	=	*outdoor temperature, K*
h	=	*building height, m*

$$P_{sf} = P_s * ThermalDraftCoefficient$$

Suggested Thermal Draft Coefficient [ASHRAE 1989 and AIVC 1982]

	Thermal Draft Coefficient
Building with isolated and sealed floors (tight)	0.6 to 0.7
Building with semi-isolated floors (average)	0.7 to 0.85
Buildings with poorly isolated floors and several through shafts (loose)	0.86 to 0.95
Most high-rise residential buildings with 2 elevator shafts, 2 stairways, garbage and service shafts	0.80 to 0.90

Combined Infiltration Driving Forces

$$P_h = P_{w_h} + P_{s_h} + P_{vent}$$

$$Q_{ws} = (Q_w^2 + Q_s^2)^{1/2}$$

where,

Q_{ws}	=	*total air infiltration, L/s*
Q_w	=	*infiltration due to wind, L/s*
Q_s	=	*infiltration due to stack, L/s*

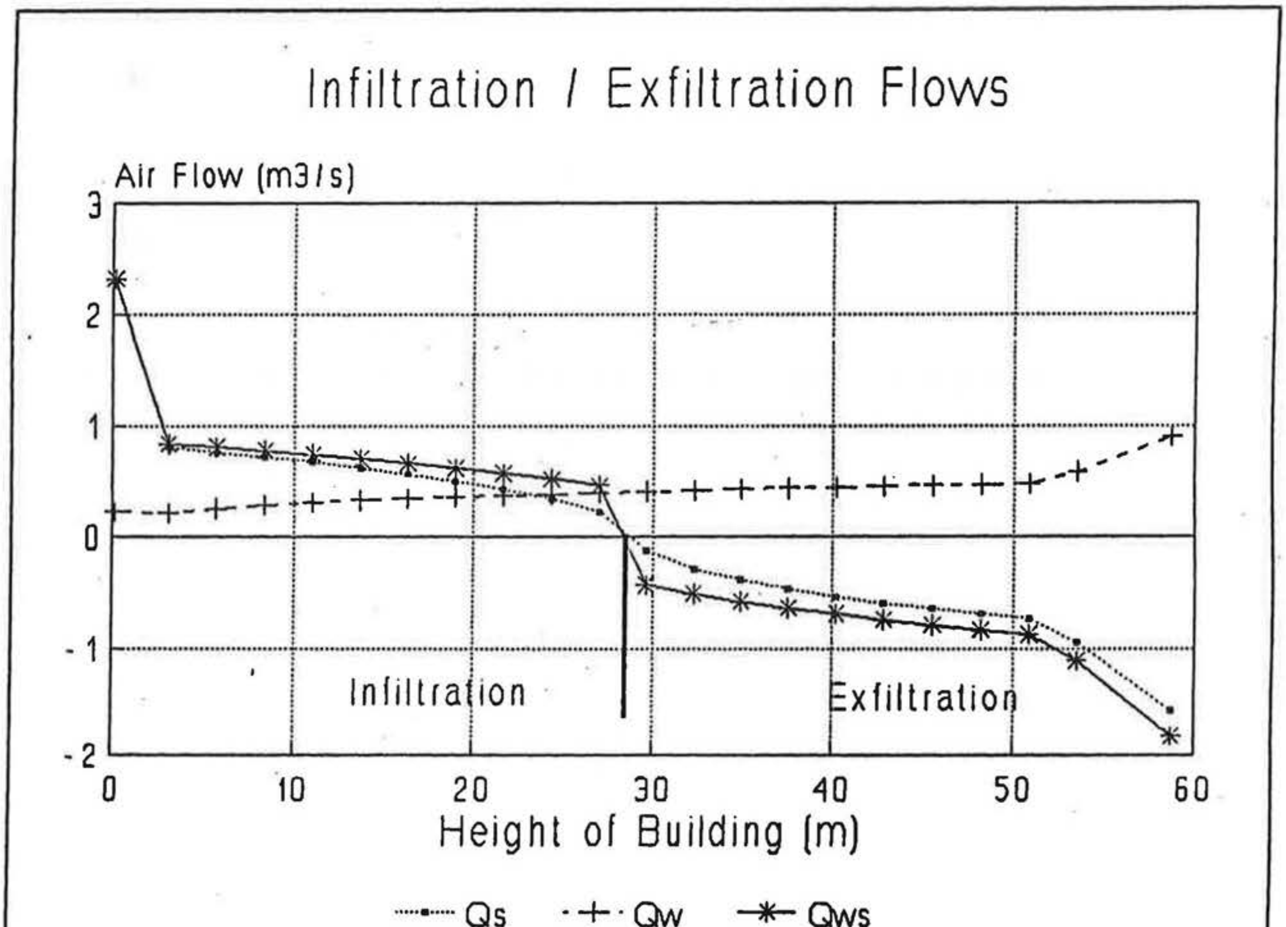


Figure 1: A typical estimation of Q_s, Q_w and Q_{ws} for a 20 storey building.

The leakage paths on the exterior building envelope and shafts are classified as following:

- **the basement floor plus ground floor [A_G],**
- **typical floor [A_T], and**
- **top floor and penthouse [A_R].**

The infiltration rate Q_i and exfiltration rate Q_o through the exterior wall can be expressed as the following with the inner/outer pressure differential ΔP (Pa) and leakage area A (m^2):

$$Q_i = A_G\sqrt{(2|\Delta P_G|/\rho)} + \sum_{j=2}^{M-1} A_{Tj}\sqrt{2|\Delta P_j|/\rho)} \qquad (1)$$

and

$$Q_o = \sum_{j=M}^{N} A_{Tj}\sqrt{2|\Delta P_j|/\rho)} + A_R\sqrt{(2|\Delta P_R|/\rho)} \qquad (2)$$

The airflow balance is

$$Q_i = Q_o \qquad (3)$$

where,	**Q**	**= Airflow rate, m^3/s**	***i* - in-flow, *o* - out-flow**
	A	**= leakage area, m^2**	
	ρ	**= air density, kg/m^3**	
	ΔP	**= pressure difference across building envelope, Pa**	

Calculation of Peak Heating Demand due to Infiltration

$$q = Q_I \rho C_p \Delta T$$

where,

q	=	*heat load due to air infiltration, W*
Q_I	=	*air inflow rate, L/s*
ρ	=	*air density, kg/m³ (about 1.2)*
C_p	=	*specific heat of air, kJ/(kg C) (about 1.0)*

$$T_b = T_I - \frac{q_{internal}}{UA}$$

where, T_b *is the balance point temperature used for infiltration calculation. It depends on the thermostat set temperature, conductance heat losses through the building envelope (excluding infiltration losses), and internal loads* ($q_{internal}$) *due to lighting, occupancy and other equipment.* T_I *is the thermostat set temperature.*

UA is combined transmission and ventilation loss, W/K per m^2 *of floor area*

$q_{internal}$ *is the internal heat gain from lights, people, equipment and solar, W per* m^2 *of floor area*

$$HL_{Infiltration(reduction)} = S_{effectiveness} * q$$

$$E = (HL_{Infiltration(reduction)} * DD * C)/(\Delta T)$$

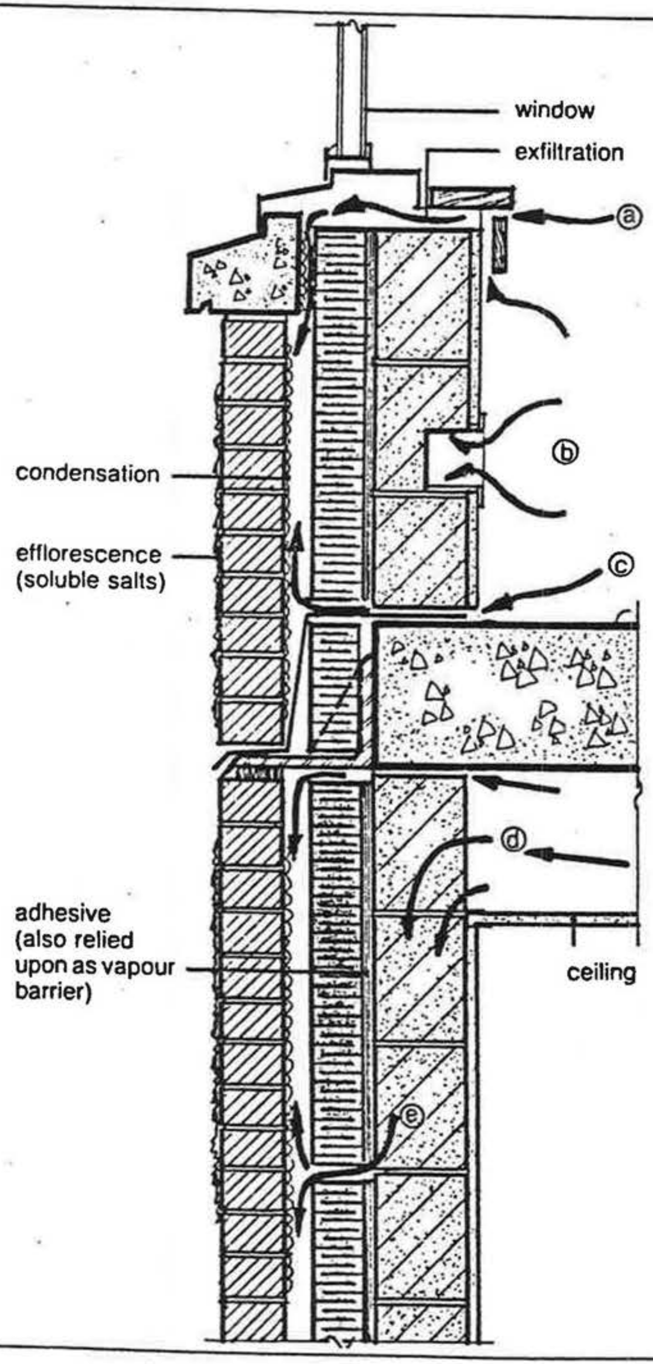
where,

E	= *Annual reduction space heating energy, kWh*
DD	= *Annual heating degree days, (C - days)*
ΔT	= *Design temperature difference, C (For Toronto, 38 C)*
C	= *C-factor, Credit factor, hours/day*

Air Leakage Assessment Procedure

Steps:

- Building inspection and assessment of air leakage paths
  - climate and exposure, building form and type, floor by floor leakage paths, openings, shafts...
  - visual inspection and simple in-situ tests
  - building component air-leakage characteristics
  - air quality and moisture assessment
- Estimation of air leakage rate at peak design conditions
  - stack and wind pressure distribution
  - assigning leakage characteristics
  - estimation of air leakage rate and sealing priorities
  - estimation of heating load due to air leakage
- Assessment of cost-benefits and implementations



(a) windows
(b) electrical boxes
(c) floor joints
(d) slab and wall joints
(e) interstitial air passage

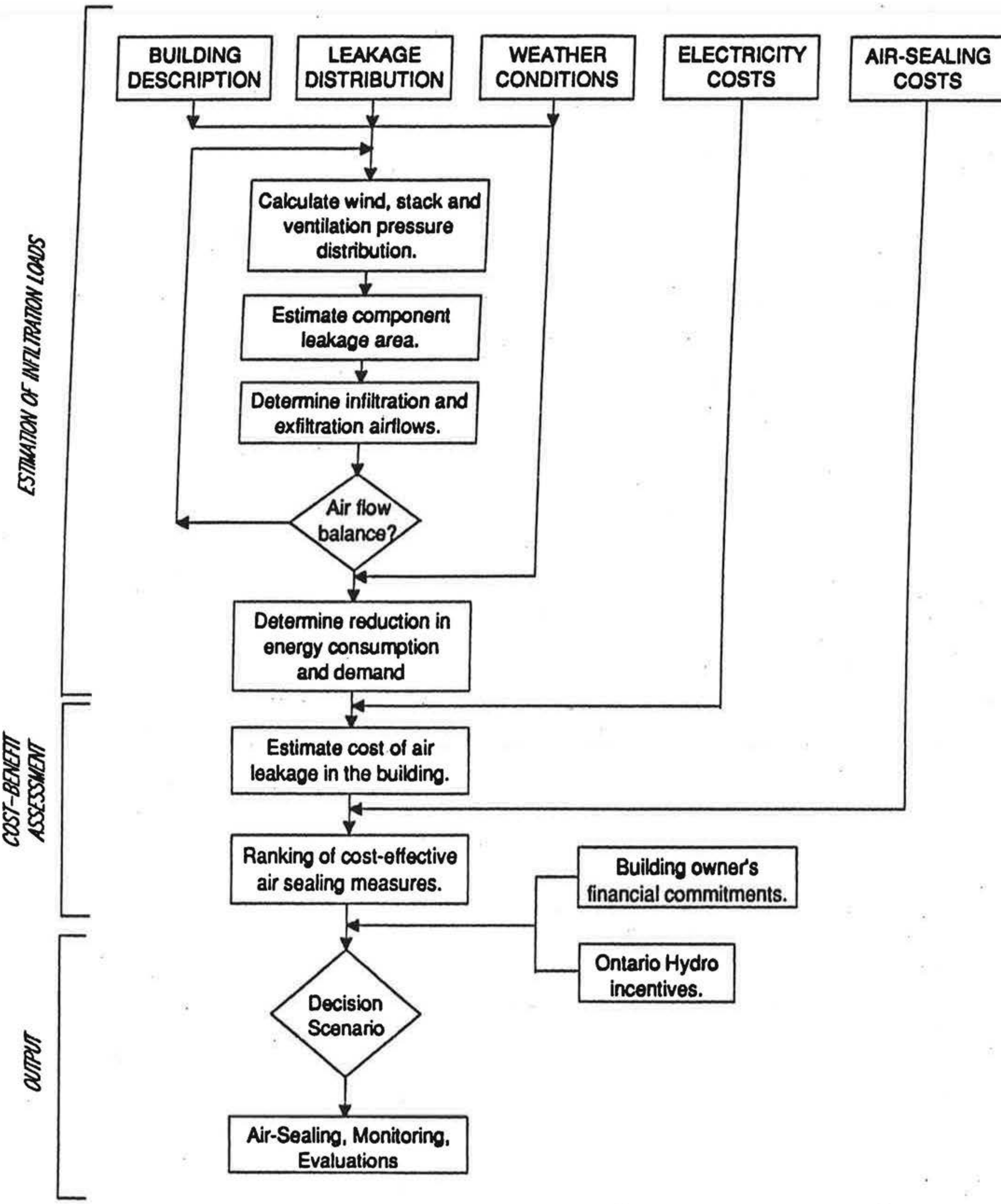
Air-Sealing Priorities

The following air-sealing priorities are evaluated:

- Windows
- Doors
- Building Envelope
- Shafts
- Miscellaneous

- top and bottom 1/3 rd of the building

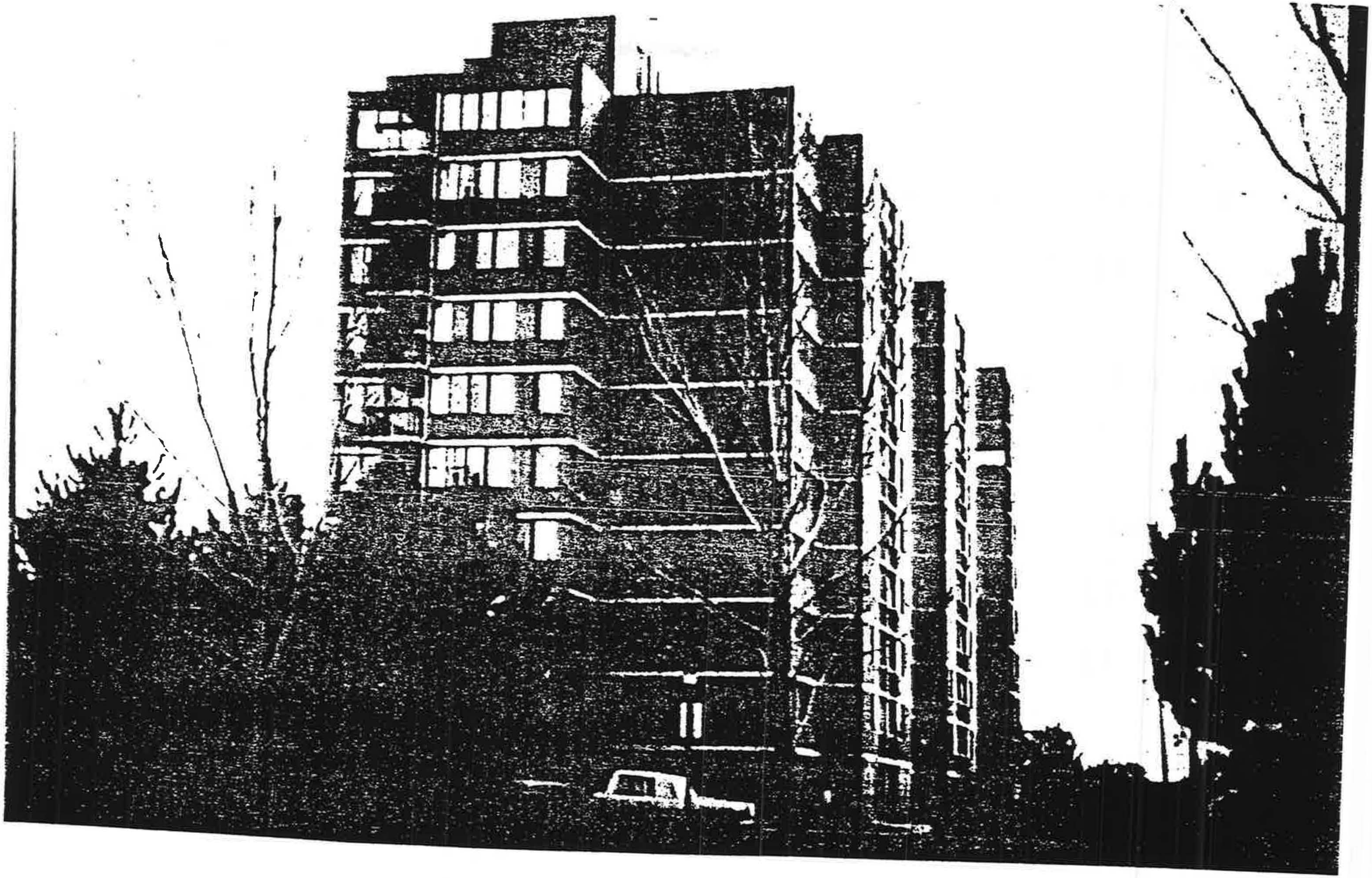
Figure 1. Procedure for Air Leakage Assessment and Control in Buildings

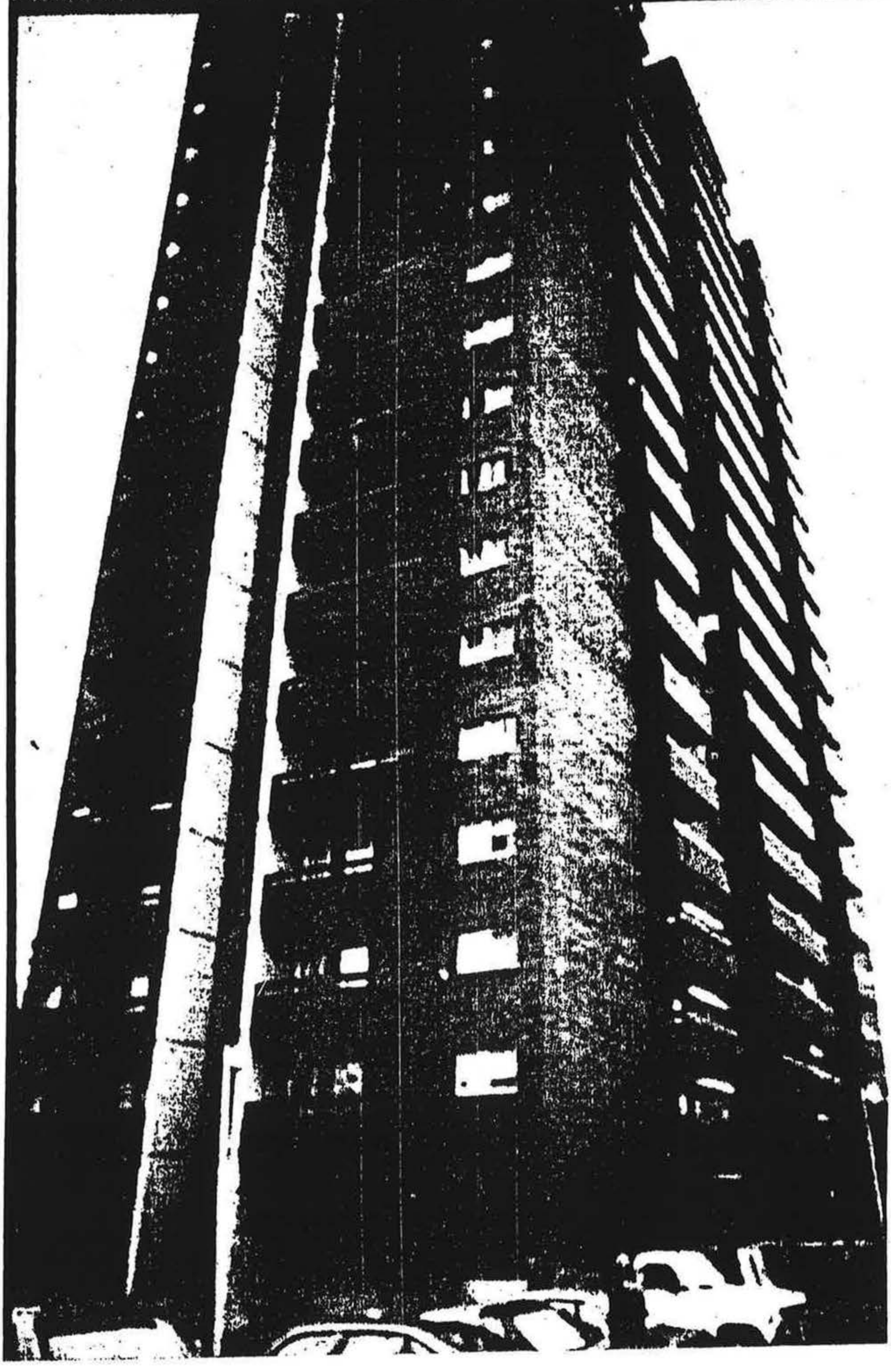


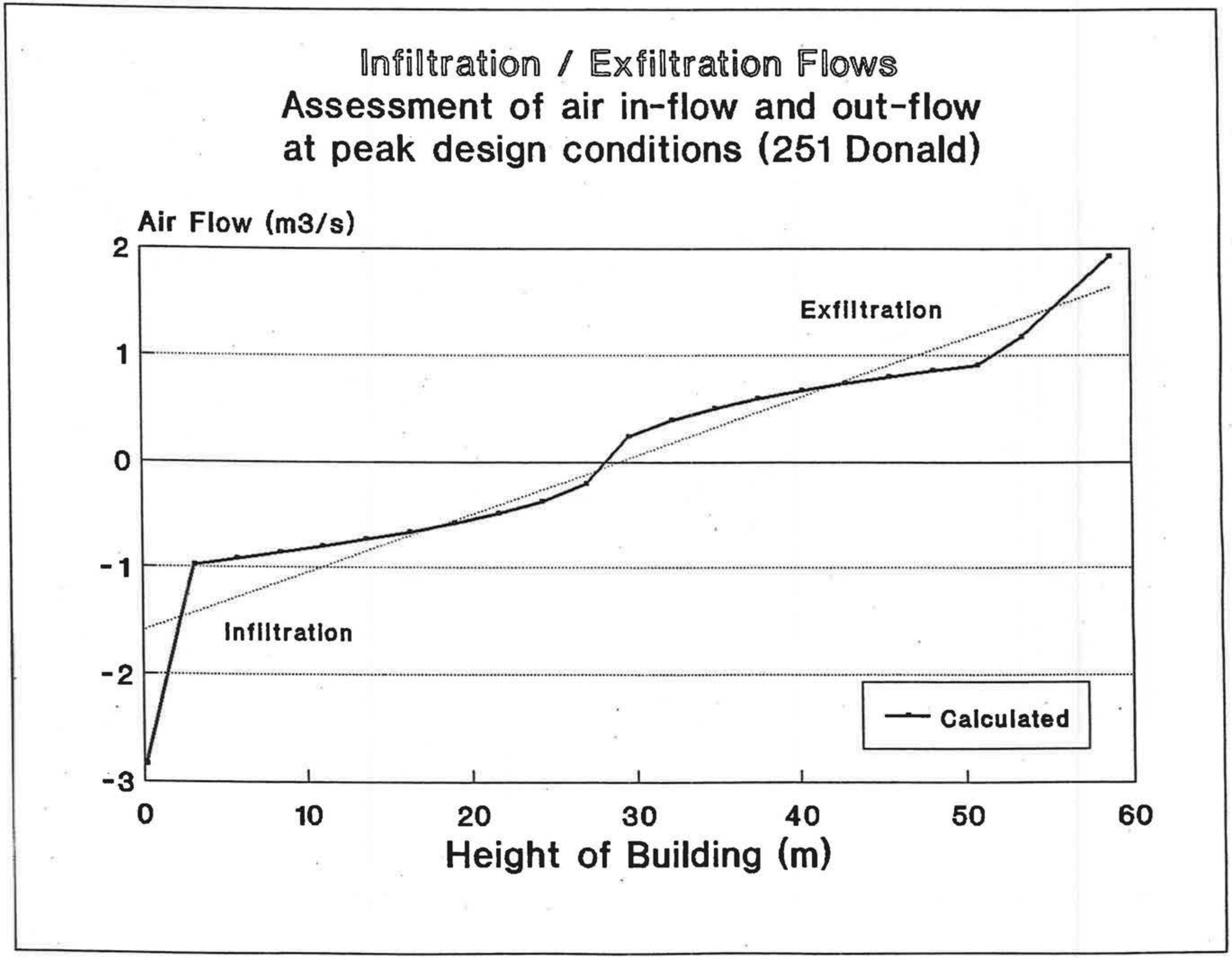
Air Leakage Assessment Procedure

The procedure assists in:

- identifying the need for air leakage control retrofits
- determining the peak air leakage rate in the building
- estimating the potential reduction in peak demand and energy consumption
- defining the air-sealing priorities and effectiveness for achieving maximum ratio of reduction in kW to the air-sealing costs
- analyzing cost-benefits and preparing the work plan
- evaluating the impact of ALC retrofits on DSM objectives





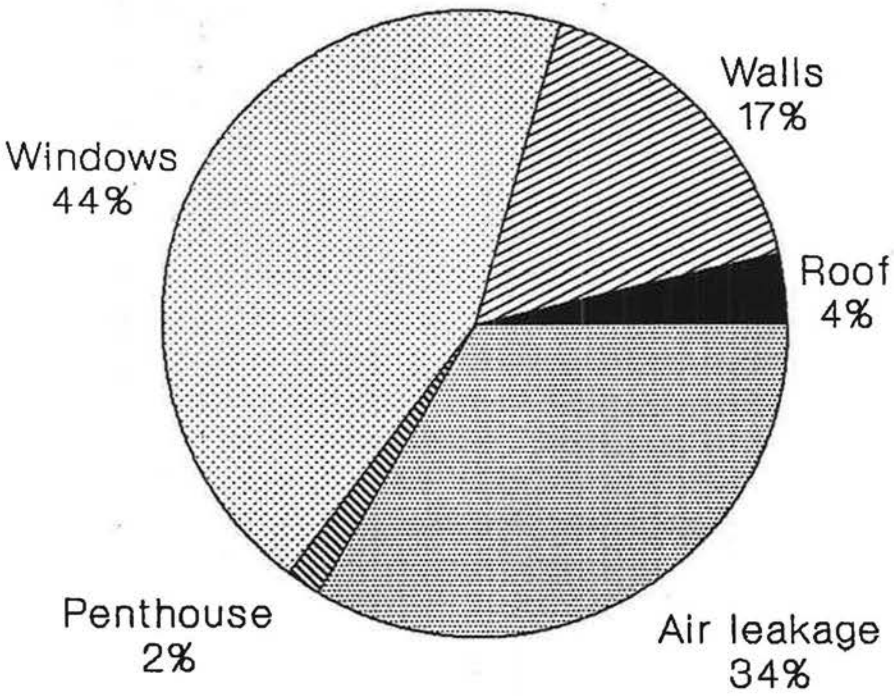


Infiltration / Exfiltration Flows
Assessment of air in-flow and out-flow at peak design conditions (251 Donald)
Air Flow (m3/s)
2
1
0
-1
-2
-3
Exfiltration
Infiltration
Calculated
0
10
20
30
40
50
60
Height of Building (m)

Field Demonstration and Validation

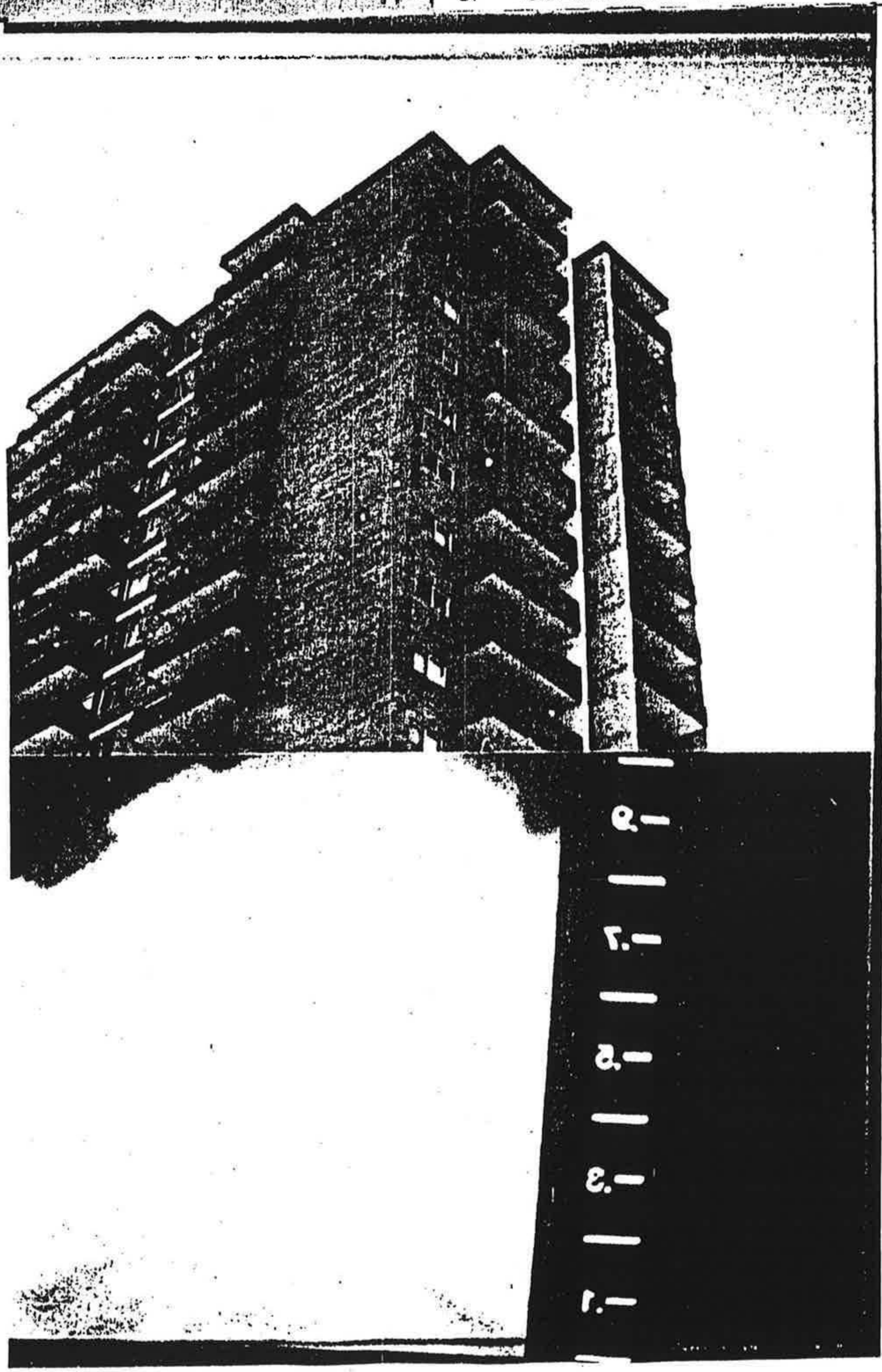
- Two buildings - 10 storey Bridleview and
  21 storey Donald Street
- Assessment of air leakage and potential reductions in peak demand, and priorizing air-sealing work
- "Before" and "After" tests
  - Airtightness of building shell
  - Indoor air quality
  - Energy and power monitoring
- Analyses of data and comparison with predictions
- Cost-benefit assessment

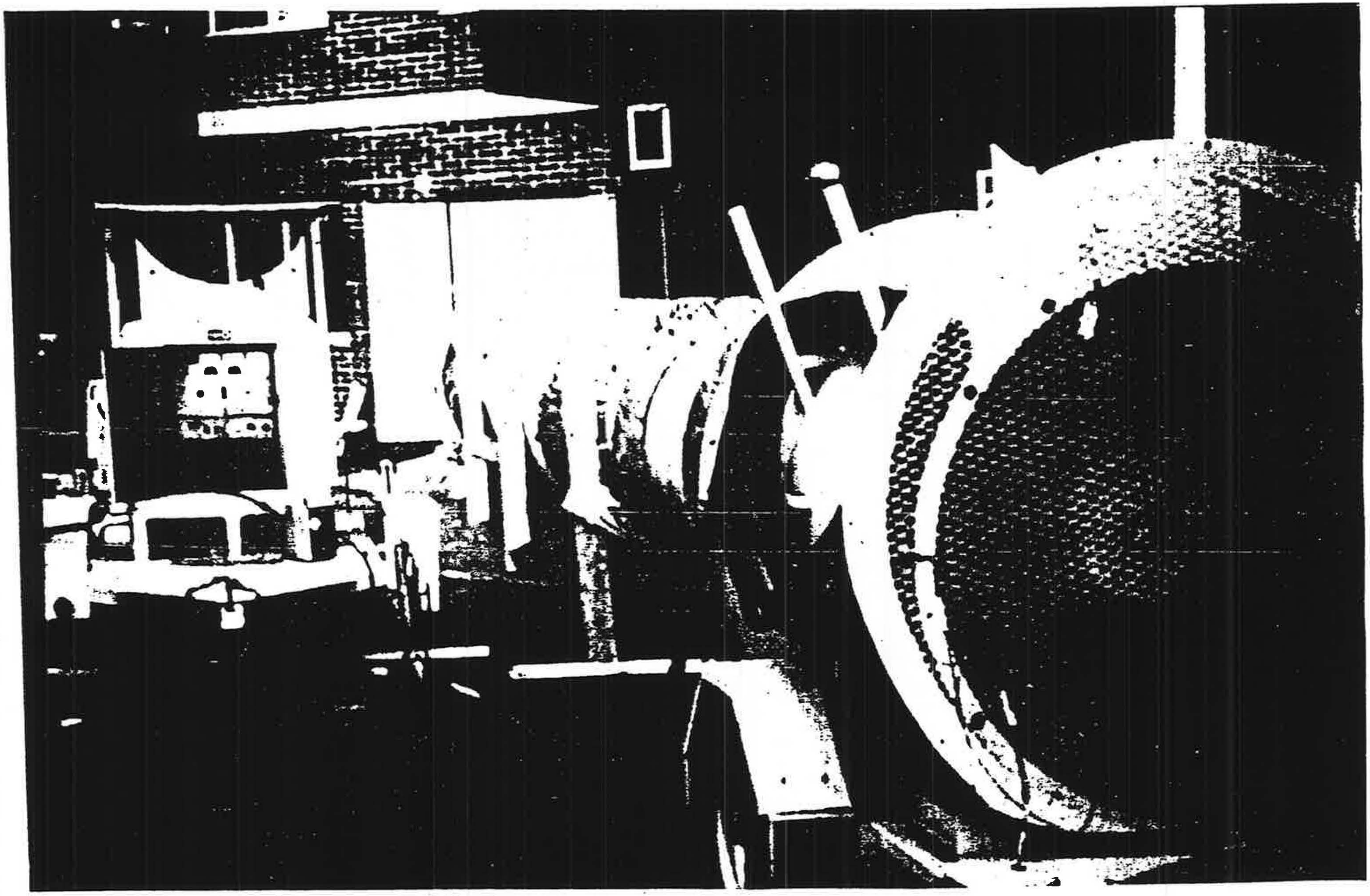
Space Heating Demand Calculations
Bridleview Building

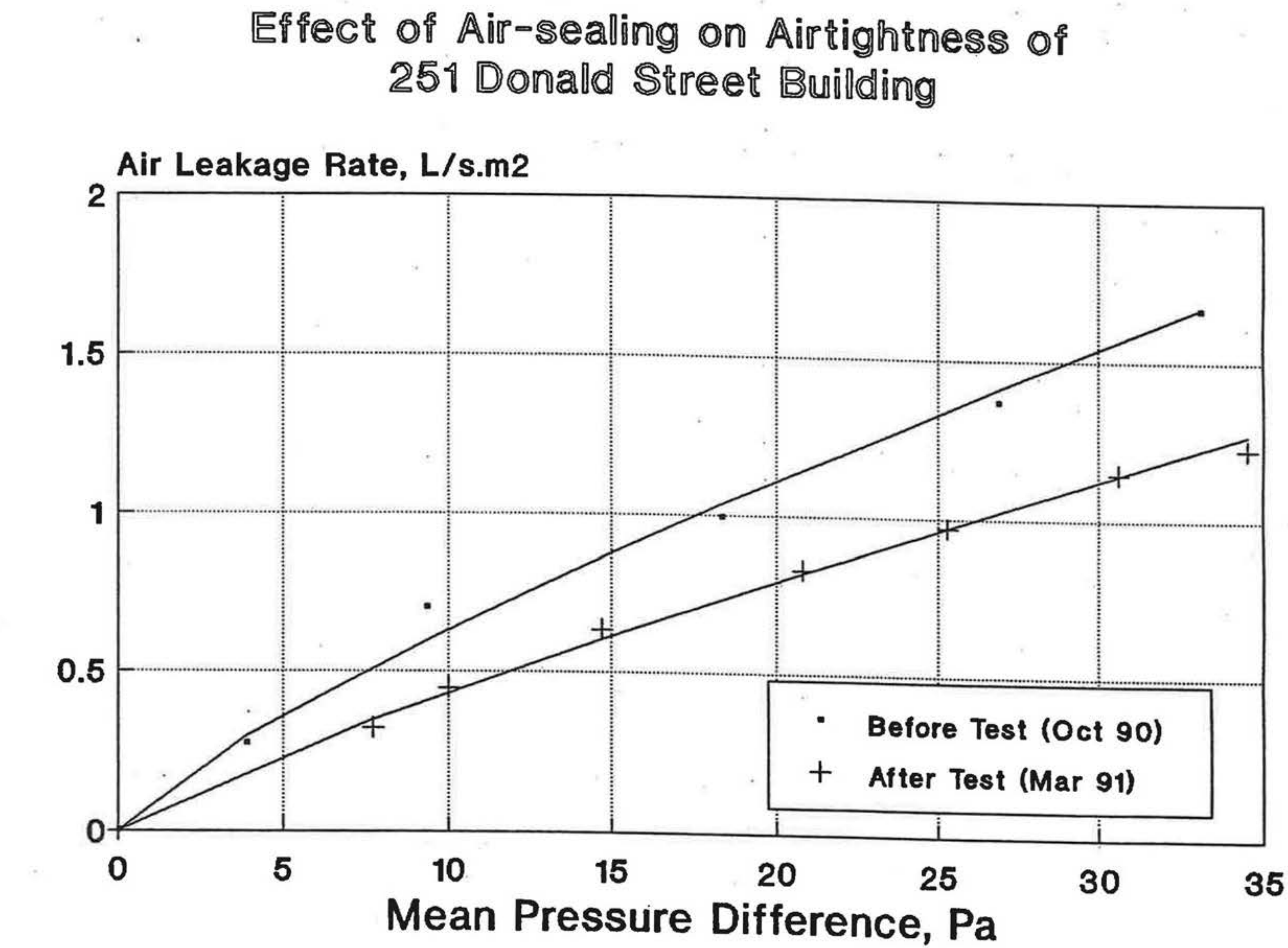


(electric only)

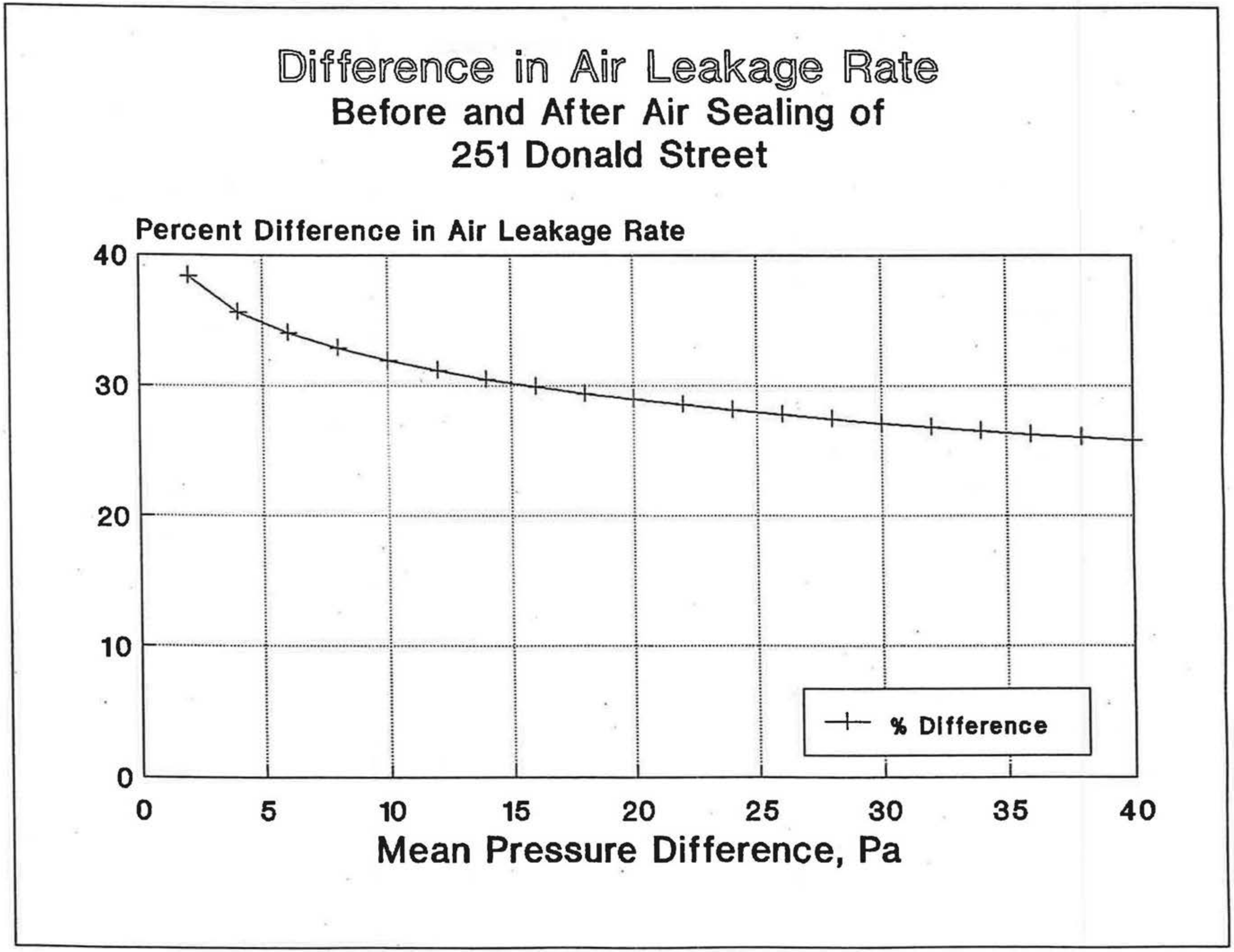
UP SUPERIÉURE OBEN おもて

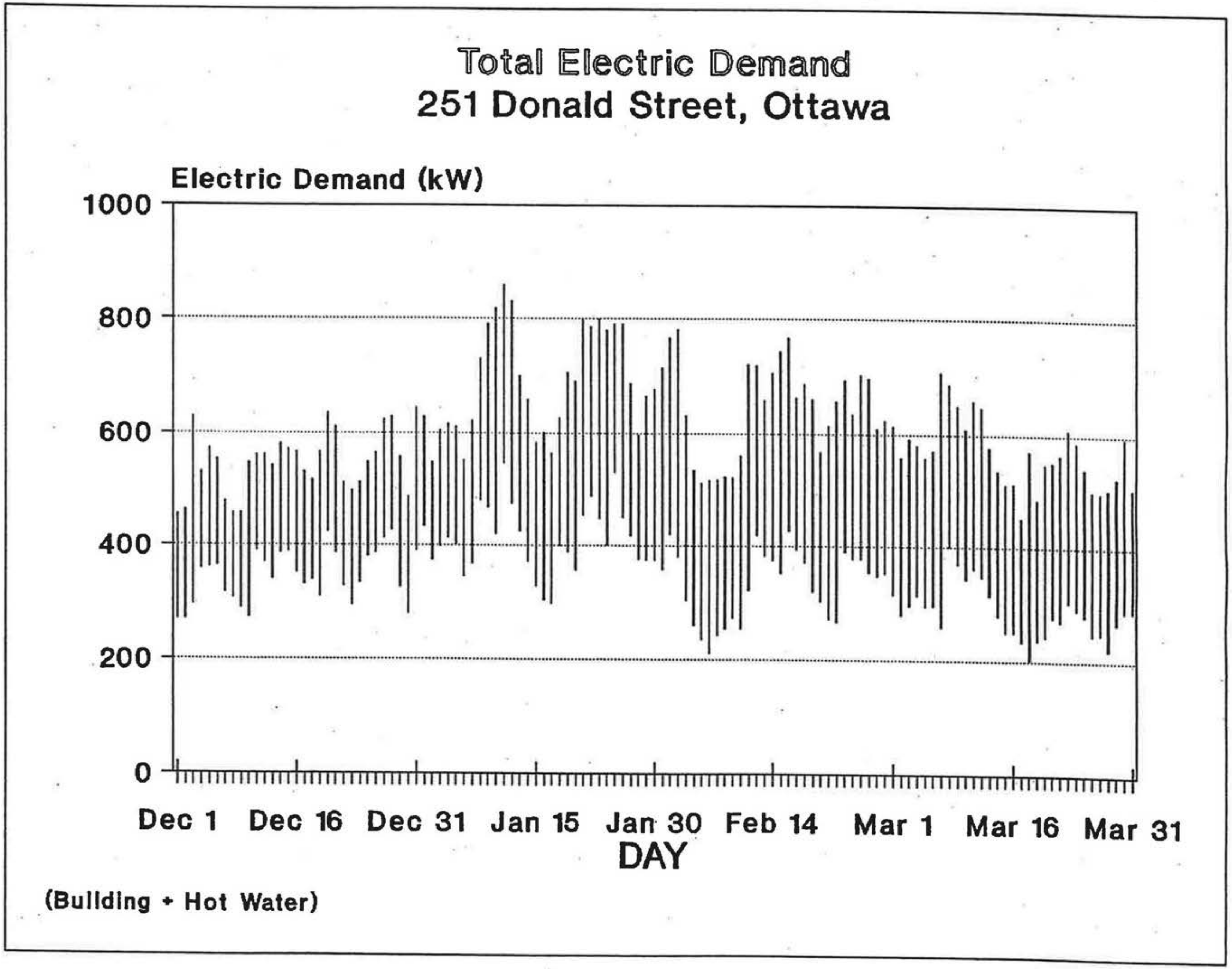


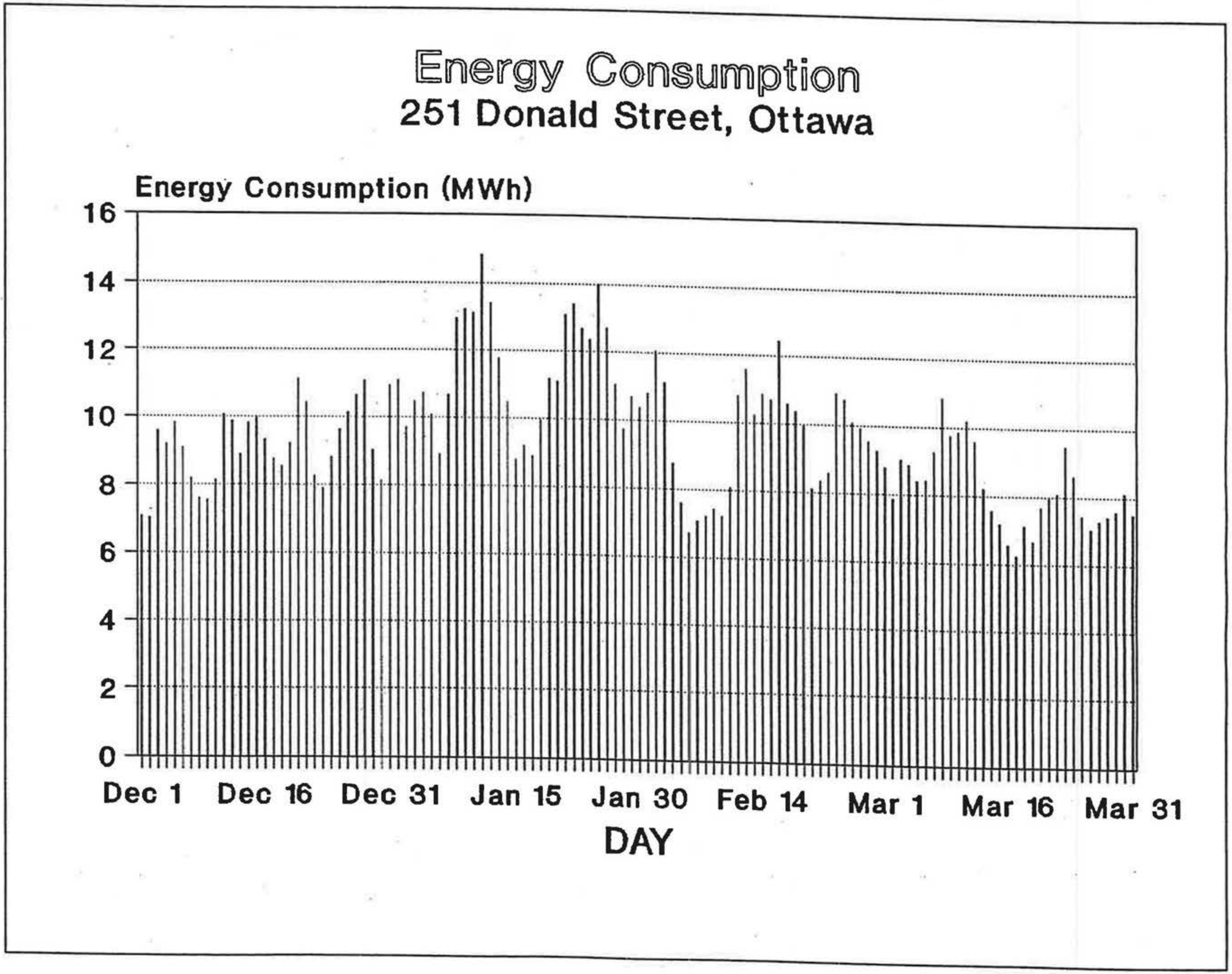


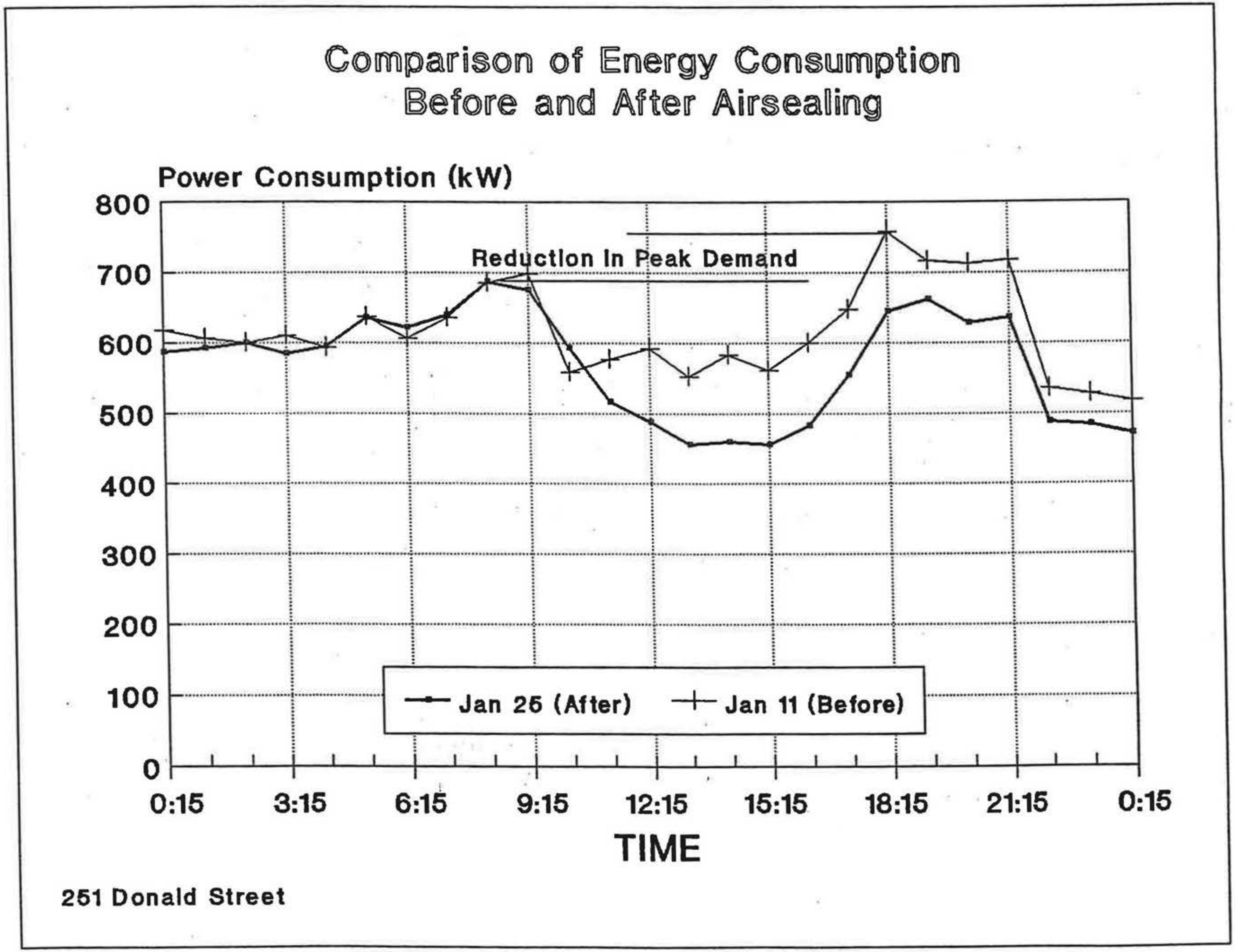


Before Test: Q = 0.0983 (Delta P)^0.809
After Test: Q = 0.0580 (Delta P)^0.872

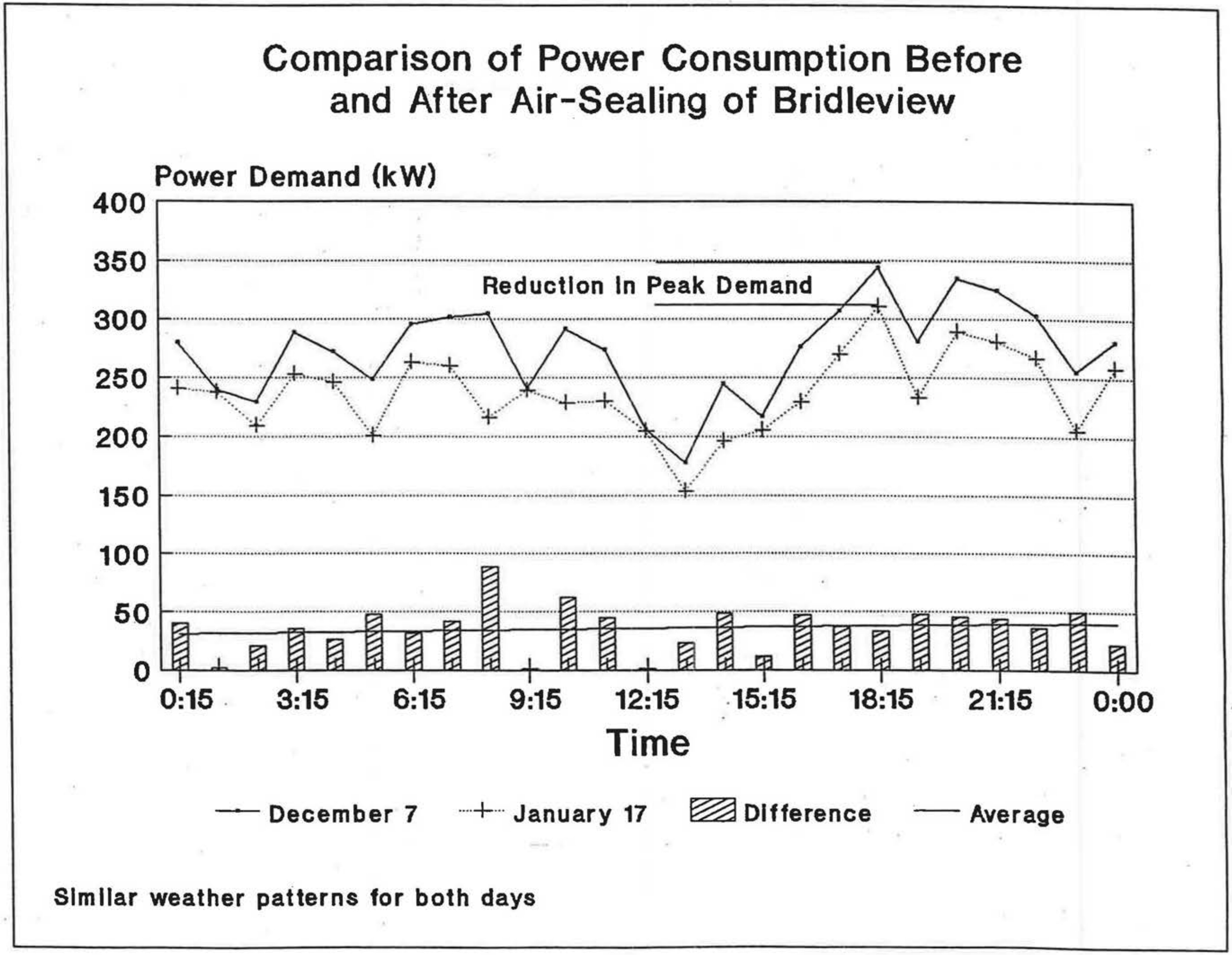

Difference in Air Leakage Rate
Before and After Air Sealing of
251 Donald Street
Percent Difference in Air Leakage Rate
40
30
20
10
0
0
5
10
15
20
25
30
35
40
Mean Pressure Difference, Pa
% Difference


Total Electric Demand
251 Donald Street, Ottawa
Electric Demand (kW)
1000
800
600
400
200
0
Dec 1
Dec 16
Dec 31
Jan 15
Jan 30
Feb 14
Mar 1
Mar 16
Mar 31
DAY
(Building + Hot Water)

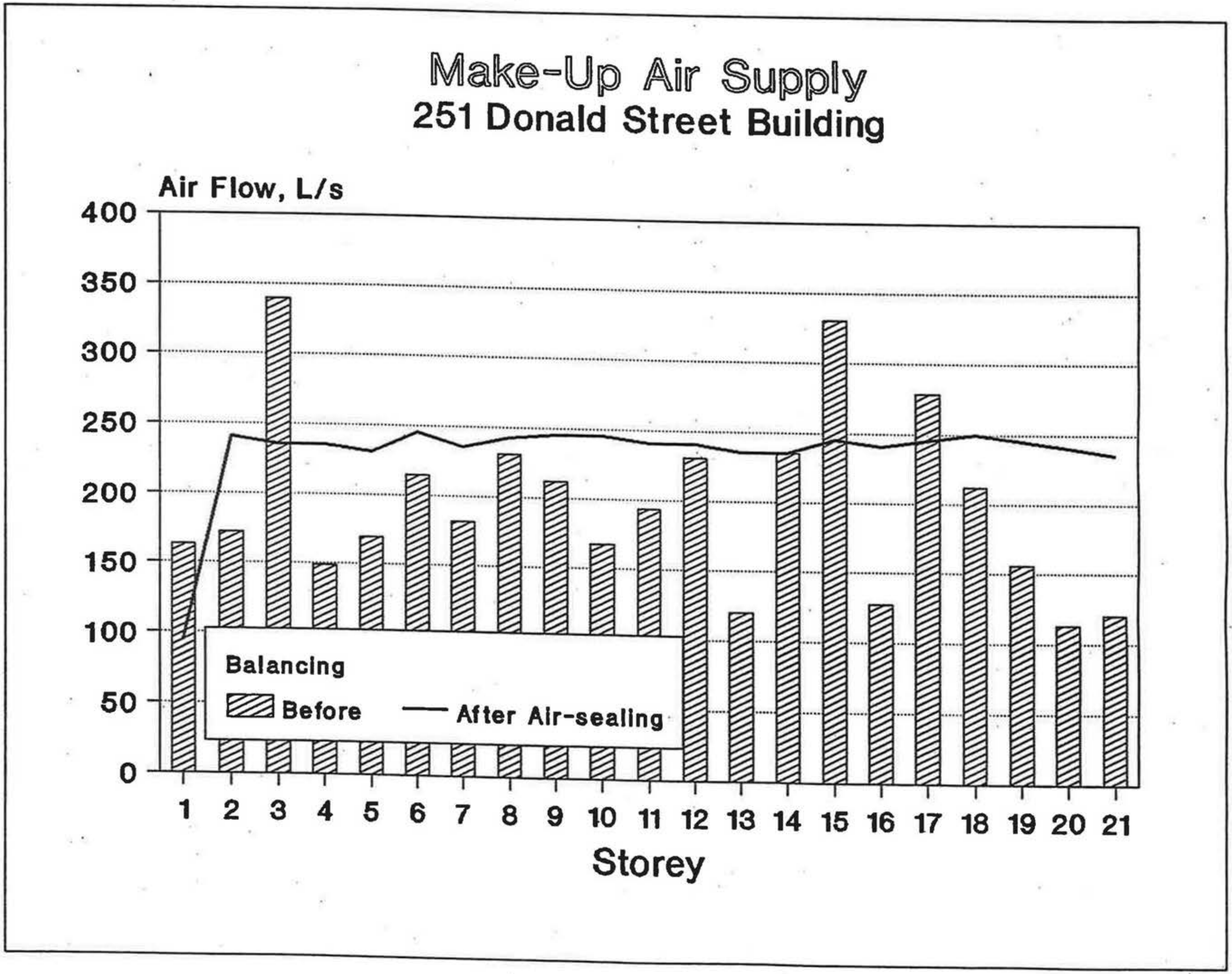

Energy Consumption
251 Donald Street, Ottawa
Energy Consumption (MWh)
16
14
12
10
8
6
4
2
0
Dec 1
Dec 16
Dec 31
Jan 15
Jan 30
Feb 14
Mar 1
Mar 16
Mar 31
DAY


Comparison of Energy Consumption
Before and After Airsealing
Power Consumption (kW)
800
700
600
500
400
300
200
100
0
Reduction In Peak Demand
Jan 25 (After)
Jan 11 (Before)
0:15
3:15
6:15
9:15
12:15
15:15
18:15
21:15
0:15
TIME
251 Donald Street

H-25

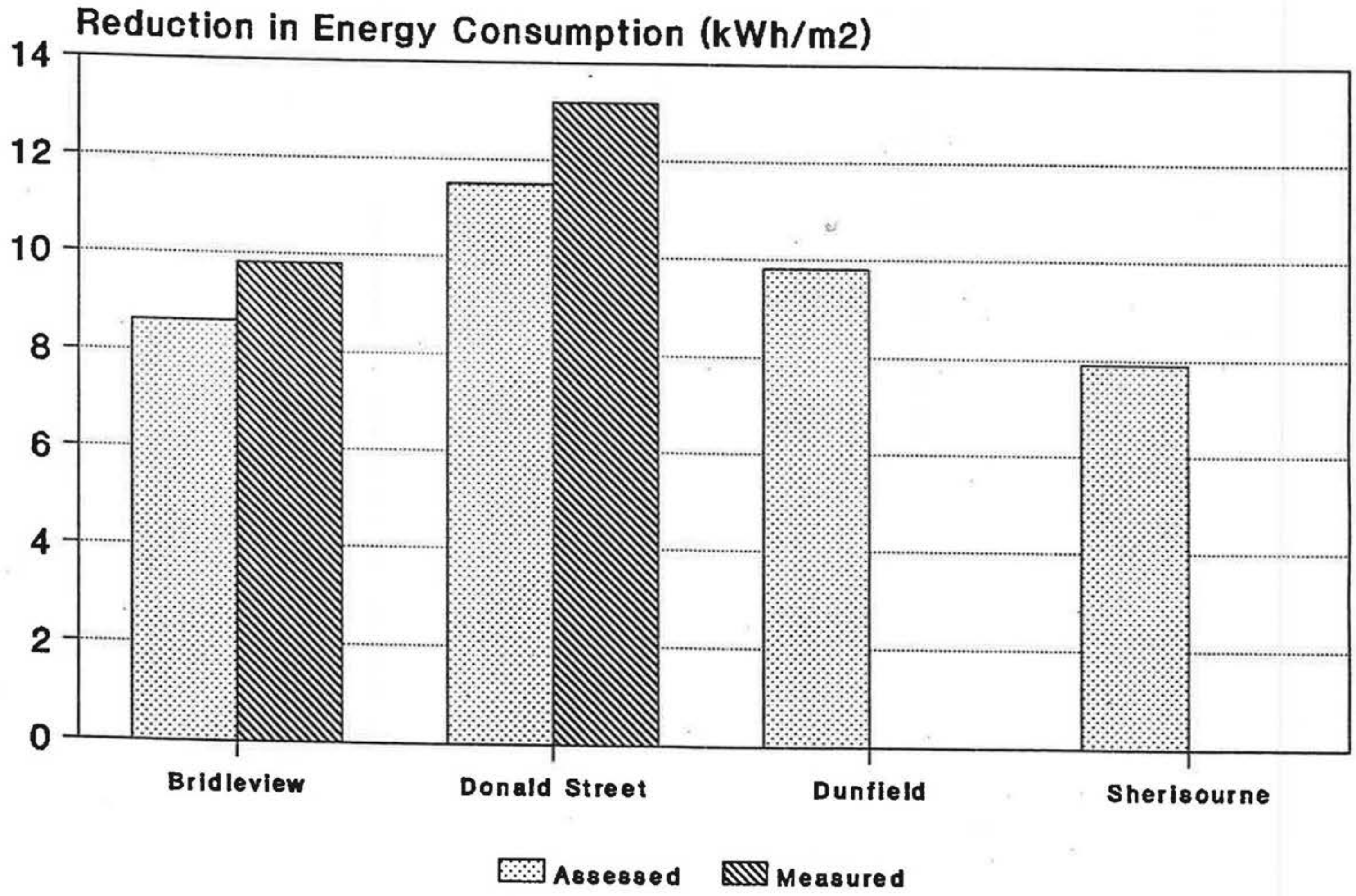


Comparison of Power Consumption Before and After Air-Sealing of Bridleview
Power Demand (kW)
400
350
300
250
200
150
100
50
0
Reduction in Peak Demand
0:15
3:15
6:15
9:15
12:15
15:15
18:15
21:15
0:00
Time
December 7
January 17
Difference
Average
Similar weather patterns for both days

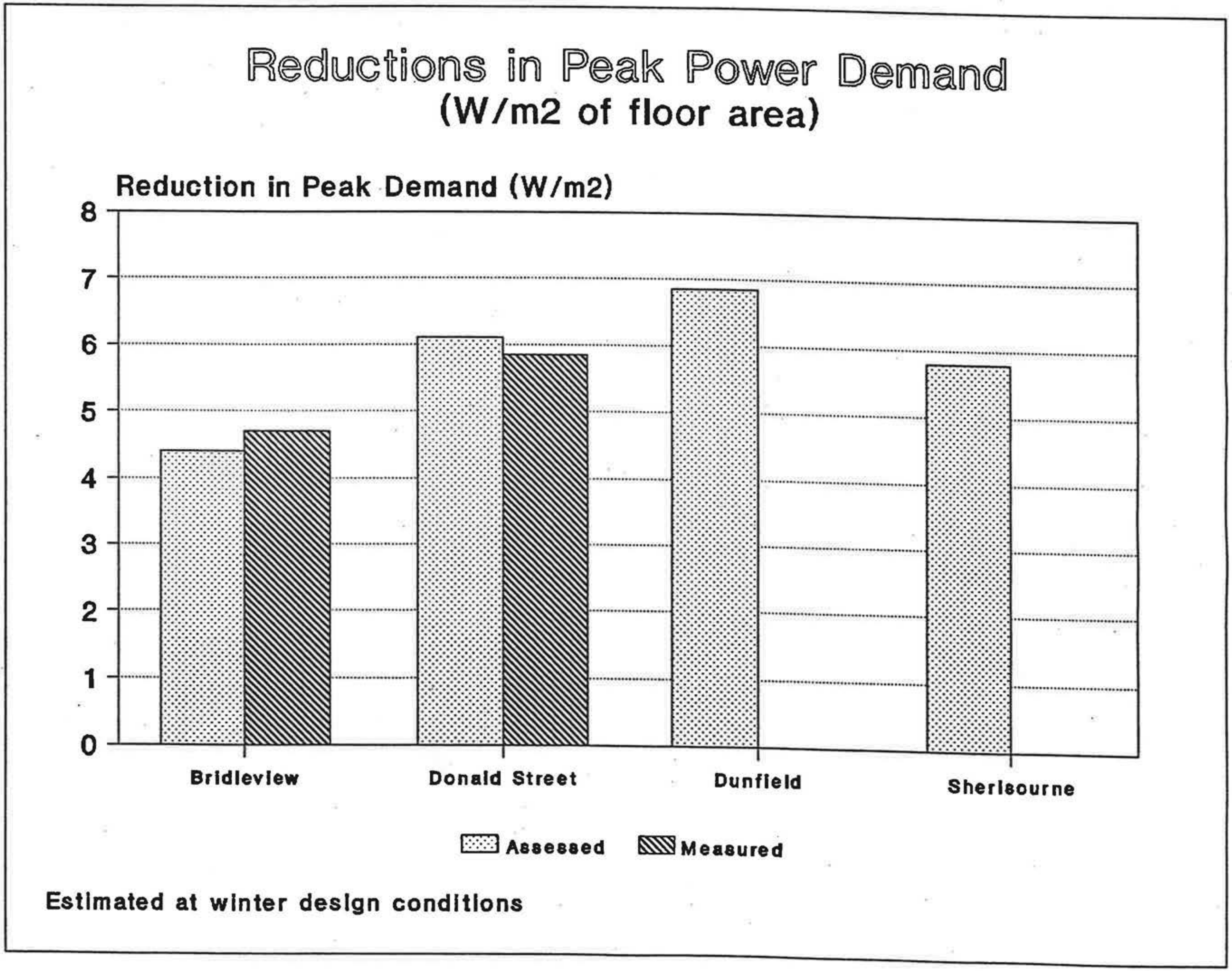

Make-Up Air Supply
251 Donald Street Building
Air Flow, L/s
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Storey
Balancing
Before
After Air-sealing

H-27

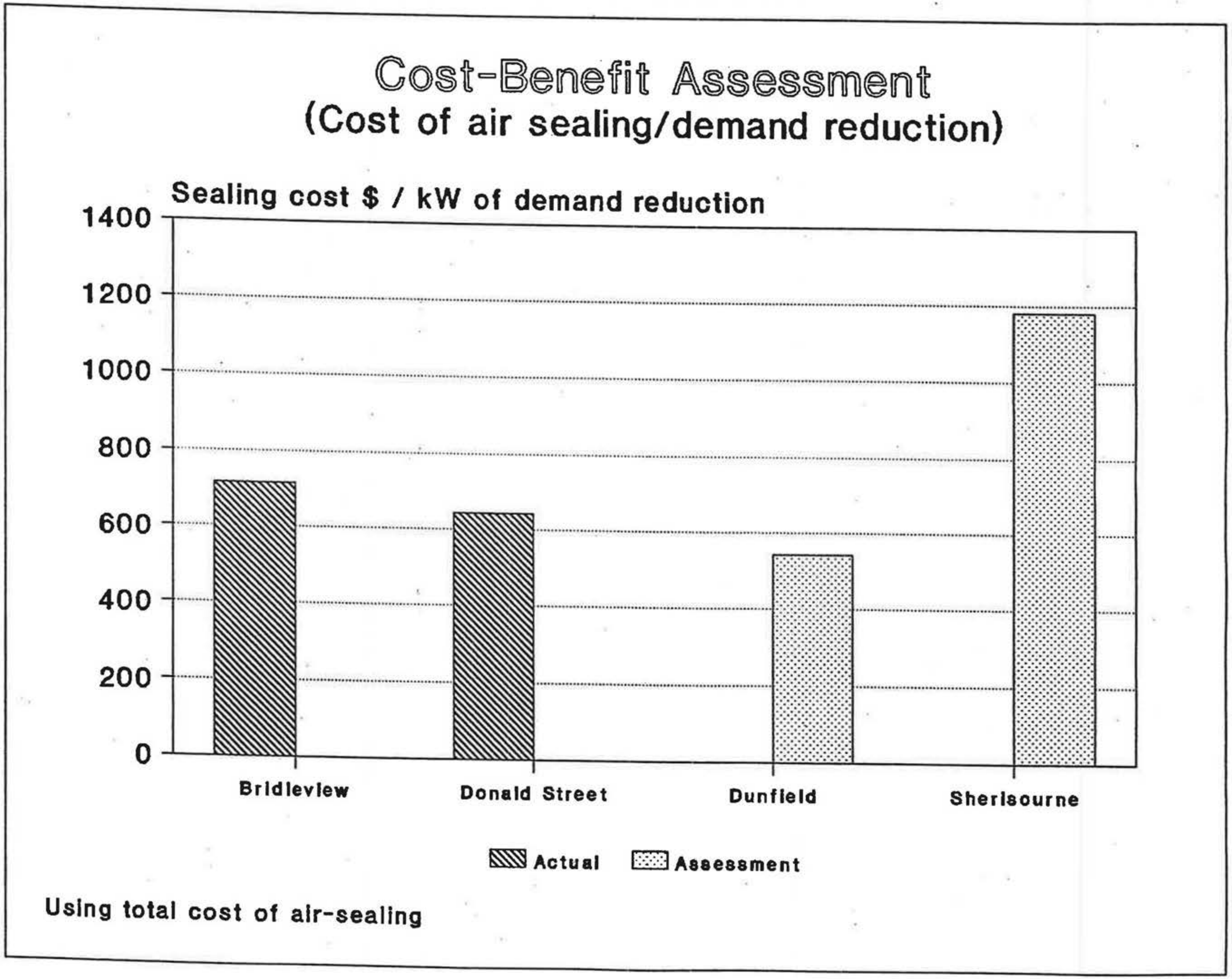
Reductions in Heating Energy Consumption
(kWh/m2 of floor area)



For the heating season


Reductions in Peak Power Demand
(W/m2 of floor area)
Reduction in Peak Demand (W/m2)
8
7
6
5
4
3
2
1
0
Bridleview
Donald Street
Dunfield
Sherisourne
Assessed
Measured
Estimated at winter design conditions

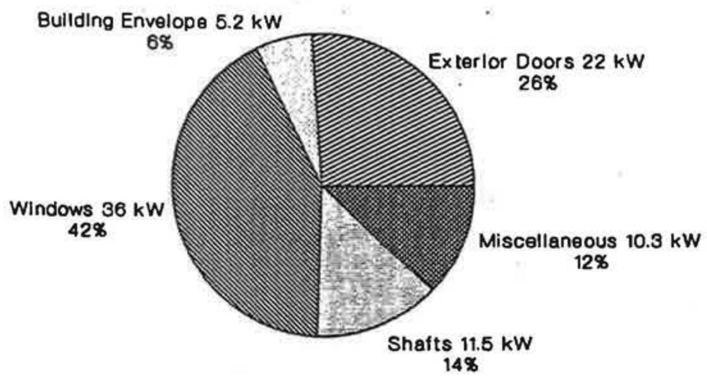
H-29



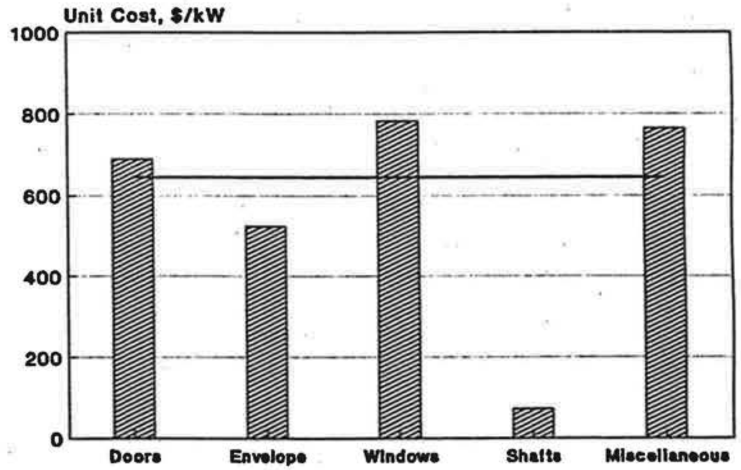
Cost-Benefit Assessment
(Cost of air sealing/demand reduction)
Sealing cost $ / kW of demand reduction
1400
1200
1000
800
600
400
200
0
Bridleview
Donald Street
Dunfield
Sherlsourne
Actual
Assessment
Using total cost of air-sealing

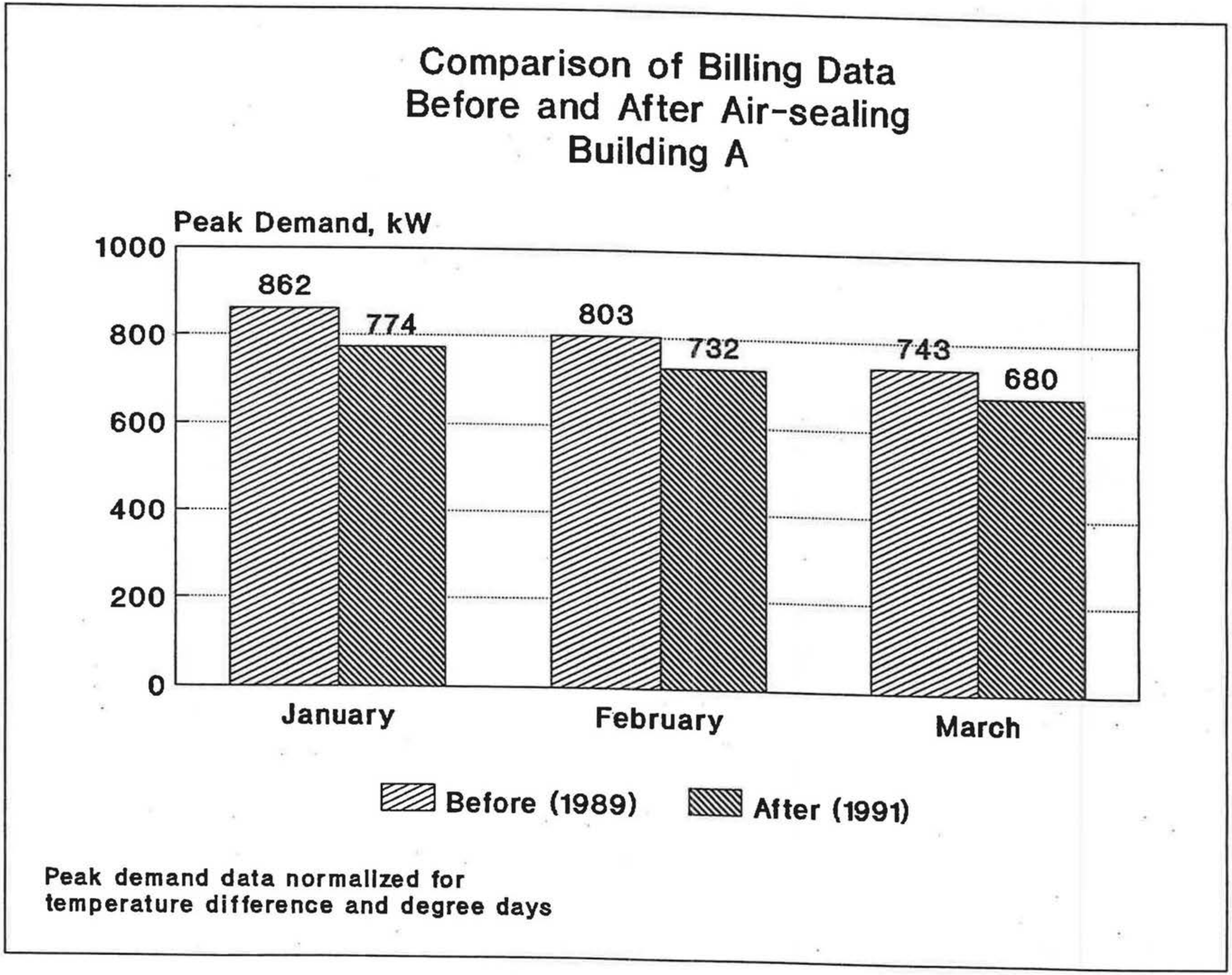
Cost-Benefit Assessment
251 Donald Street

Reductions in Peak Demand (Peak Design Conditions)



Unit Cost of Air-Sealing (Peak Design Conditions)





Comparison of Billing Data
Before and After Air-sealing
Building A
Peak Demand, kW
1000
800
600
400
200
0
862
774
803
732
743
680
January
February
March
Before (1989)
After (1991)
Peak demand data normalized for
temperature difference and degree days

Indoor Air Quality Results

The following components were monitored:

	After Air-Sealing
1. Indoor room temperature	slightly increased
2. Relative humidity	increased
3. Carbon dioxide	slightly increased
4. Formaldehyde	slightly increased
5. Radon (basement + ground)	no change
6. Carbon monoxide	slightly increased

Occupant survey - very few comments

No appreciable change in indoor air quality after air-sealing.

Potential energy and peak demand savings due to air leakage control in Ontario.

	Total Floor Area (Mm²)	Electric Heated		Air Leakage Contribution		Potential Reductions about 35% sealing	
		%	Area m²	Energy GWh	Peak Demand MW	Energy GWh	Peak Demand MW
High-rise Residential	76.3	39	29.76	833	545	292	191
Detached, medium rise and row houses	142	24	34.08	1,091	896	382	314
Total potential reduction with @ 35% sealing equivalence:						674	505

Using Building Stock Model - CANADA-II, Prepared by Scanada Consultants Limited for Energy, Mines and Resources Canada, 1990.

Implementation

- Pre-screening
- Field assessment, sealing priorities, cost-benefits and a work order
- Implementation of air-sealing work
- Quality control and inspection of air-sealing work
- Assessment of energy consumption after ALC

Criteria

Suggested criteria for air leakage control in electrically heated high-rise buildings:

- building has eight or more storeys
- no major renovations to building envelope
- meets criteria for indoor air quality
- owners are willing to participate

Issues

- Training:
  assessors
  air-sealing contractors
- Quality control
- Verification of assessment procedure for a large number of buildings
- Program evaluation

Conclusions

- A high-rise air leakage assessment procedure has been developed and shown to be useful in predicting the effects of air leakage control retrofits and in priorizing and guiding their implementation.
- Air leakage control offers the potential to reduce the winter on-peak demand by 4 to 10 W/m2 of floor space - with a mean value of 6 W/m2.
- Air-sealing of the building had no negative impact on indoor air quality and human comfort.
- The total cost of air-sealing may vary from $650 to $900 depending on air-sealing priorities.
- Sealing of shafts is the most cost effective retrofit.

Further Development

- Development of a user-friendly computer program of air leakage assessment procedure
- Training modules for assessors and air-sealing contractors - manuals and videos
- Monitoring of 10 to 15 more buildings across Ontario to verify and raise confidence in assessment procedure
- Study of reliability and maintainability of air-sealing products and applications
- Design guidelines for new high-rise buildings

SYNOPSIS

Air infiltration and ventilation has a profound influence on both the internal environment and on the energy needs of buildings. In most electrically heated high-rise residential buildings, in cold climates, during the peak winter conditions (below -18 deg C ambient temperature and above 15 km/hour wind velocity), the air infiltration component contributes to heating load by 10 to 18 W/m^2 - roughly 25 to 35% of peak heating demand. Any reduction in such uncontrolled air infiltration, without sacrificing indoor air quality, will have potential to reduce the peak heating demand. To evaluate the effectiveness of air-sealing measure, the air leakage rates through the building envelope were measured both before and after the air-sealing using the large vane-axial fan. Several air quality measurements (indoor temperatures, relative humidity, CO_2, formaldehyde, radon gas) were taken in each building to assess the practical implications of air sealing on the indoor air quality and thermal comfort.

The whole building airtightness tests showed that the air-sealing of the building envelope reduced the air leakage rate by 32% in one building and 38% in other. Energy monitoring for two buildings showed the reduction in heating demand by approximately 6 W/m^2 of floor space -- 12 to 15% due to air leakage control. Indoor air quality tests showed that the air sealing had no negative impact on the general conditions of comfort and air quality in both buildings. The field implementation of air leakage control has helped to remove some of the uncertainties and shown the potentials for conservation are indeed considerable. This paper presents the field tests and results, and suggest a procedure for the use by air-sealing practitioners to evaluate different air-sealing strategies.

APPENDIX G: SUMMARY OF PROJECT

Scanada

POWER AND ENERGY SAVINGS THROUGH AIR LEAKAGE CONTROL IN HIGH-RISE BUILDINGS

Energy audits and assessments of four high-rise residential buildings in Ontario showed that the peak space heating demand varies from 35 to 65 W/m^2 of floor space. During peak winter conditions, the air leakage component contributes to the heating load by 10 to 18 W/m^2 - roughly 25 to 35% of the peak heating demand. The control of air leakage has become recognized as a key element in achieving energy conservation. Concerned especially with reducing peak power demand, Ontario Hydro is exploring air leakage control of high-rise buildings as a component of its DSM strategy.

This project was initiated in July 1990 by Scanada Consultants Limited of Ottawa and CanAm Building Envelope Specialists Inc. of Mississauga. Objectives were to develop an air leakage assessment procedure and to demonstrate and test the impact of air leakage control measures in the field.

The project accomplished the following: (i) it developed and validated the field procedures necessary to identify and assess the air leakage rate in buildings of eight storeys and higher; (ii) it established a procedure to evaluate the various air leakage control strategies in terms of their potential cost benefits; and (iii) it demonstrated air leakage control in two high-rise residential buildings and its resulting impact on peak power demand, energy consumption, indoor air quality, and of course airtightness. Two more case studies of high-rise buildings were added to show the implementation of the assessment procedure.

The simplified air leakage estimation procedure is based on equivalent air leakage area and local net pressure distribution. The air leakage rate at a given location depends on the driving forces (stack, wind and mechanical ventilation) and the characteristics of the opening in the building envelope. A simplified network of air-flow paths can be established using the following information: climate and exposure, building types, building form, building dimensions, surface to volume ratios, shafts, envelope types, windows and doors, envelope crack lengths, openings, and make-up air strategies. The algebraic sum of air-flow through these paths must always be equal to zero. By applying the mass balance equation, the component of air infiltration which would occur during the peak winter condition can be determined. This air-flow rate is responsible for the space heating load due to uncontrolled infiltration. Any reduction in this infiltration flow should decrease the heating requirements for the building. The procedure has been simplified and developed into a practical application tool which will be utilized by assessors and air leakage control contractors. The procedure has been assembled in the following parts and a manual was prepared to guide an assessor through the assessment procedure.

- Part A. Identification and Pre-Screening of a Building
- Part B. Building Audit and Field Inspection
- Part C. Estimation of the Uncontrolled Air Leakage Component
- Part D. Determination of Air Sealing Priorities
- Part E. Development of Work Plan for Air Sealing of the Building.
- Part F. Quality Control and Assessment of Air Leakage Control Retrofits

The field results in two high-rise buildings can be summarized as follows: (i) the air leakage control offered a reduction in peak space heating demand of 4 to 10 W/m^2 of floor space depending on the location and building characteristics -- i.e., 11 to 16% of total electric demand in these buildings; (ii) the air leakage assessment procedure was found to be reliable within 5 to 10% in predicting the potential reduction in peak heating demand; (iii) the indoor air quality tests performed before and after the air sealing showed that there was no negative impact on the general conditions of comfort and air quality in both buildings (in fact, the sealing of unnecessary air leaks enhances the control of air supply and reduces wastage); and (iv) the cost of air sealing per kW of demand savings varied from $650 to $900. While first developed to assess winter heating demands, the procedure is being extended to assess the peak reductions in summer cooling loads as well.