FIELD INVESTIGATION SURVEY OF AIRTIGHTNESS, AIR MOVEMENT AND INDOOR AIR QUALITY IN HIGH RISE APARTMENT BUILDINGS PRAIRIE REGION

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ABSTRACT

Field Investigation Survey of Airtightness, Air Movement, and Indoor Air Quality in High-Rise Apartment Buildings - Prairie Region, by B.W. Gulay and C.D. Stewart of Wardrop Engineering Inc., G. Proskiw of Unies Ltd., and P. Giesbrecht of National Testing Laboratories Ltd.

An investigation survey was conducted to determine air exfiltration through the building envelope, inter-suite air leakage, and the indoor air quality in two 13-storey high-rise residential apartment buildings located in Winnipeg. Air exfiltration and inter-suite air leakage testing was conducted in a representative number of adjacent suites. The effect the HVAC systems had on the two buildings was also investigated. Indoor air quality was established by means of a survey of the building's residents and by testing and monitoring for five specific pollutants.

EXECUTIVE SUMMARY

A field investigation survey was conducted for Canada Mortgage and Housing Corporation, Prairie Region, to determine air exfiltration rates through the building envelope, inter-suite air leakage, and indoor air quality, in two 13-storey high-rise apartment buildings located in Winnipeg. The major findings are as follows.

The test procedure in "Establishing the Protocol for Measuring the Air Leakage and Air Flow Patterns in High-Rise Apartment Buildings" was successfully modified to utilize two blowers. Sequential pressure masking of adjacent suites using a single fan was used to measure the airtightness and air movement in individual suites. Air leakage around the suite entry door accounted for approximately 40% of the total suite air leakage, the exterior wall and windows accounted for 30%, the partition walls for 20%, and 10% through inter-floor leakage.

The major leakage path for air movement between adjacent suites is the penetrations through the partition walls for the hot water radiant heating lines. The major leakage paths for inter-floor air leakage is through floor penetrations for the plumbing lines in the bathrooms, and electrical conduits in the kitchens.

The building's HVAC system pressurized the building envelope from 2 to 7 Pa on the lower floors, and from 10 to 12 Pa on the upper floors. This was determined by a series of pressure differential readings taken across the building envelope. Initial readings were taken with the HVAC system operating normally and were then repeated with the system shut down.

The total bathroom exhaust flow rates per floor were found to account for only 25% of the hallway supply air flow rate per floor. The remaining hallway supply air was exhausted through other locations, including exfiltration through the exterior wall and windows, leakage through the elevator shaft and stair halls, and that which was intentionally exhausted through the laundry dryer vents.

Indoor air quality measurements in both buildings of carbon dioxide, carbon monoxide, formaldehyde, and bacterial colony counts were all less than the recommended maximum guidelines set by Health and Welfare Canada.

Airborne particulates in one suite of Building A were found to exceed Health and Welfare Canada Guidelines, and five of seven suites tested in Building B greatly exceeded this guideline.

Most of the residents of Building A, approximately 80%, felt the air was too hot and dry. The measured relative humidity ranged from 12 to 27%. The measured air temperature ranged from 25 to 30°C.

Most of the residents of Building B, approximately 90%, felt the air was too hot and dry. The measured relative humidity ranged from 18 to 33%. The measured air temperature ranged from 22 to 29°C.

Enquête sur le terrain portant sur l'étanchéité à l'air, le mouvement de l'air et la qualité de l'air intérieur de tours d'habitation de la région des Prairies

Un enquête sur le terrain a été menée dans la région des Prairies pour la Société canadienne d'hypothèques et de logement en vue de déterminer les taux d'exfiltration de l'enveloppe du bâtiment, les fuites d'air entre les appartements et la qualité de l'air intérieur de deux immeubles de 13 étages situés à Winnipeg. En voici les principales constatations.

Il a été possible de modifier les méthodes d'essai de l'étude intitulée «Établissement des méthodes de mesure de l'étanchéité à l'air et des mouvements d'air dans les tours d'habitation» de manière à utiliser deux ventilateurs. Le masquage par pression séquentielle des appartements adjacents avec un seul ventilateur a permis de mesurer l'étanchéité à l'air et le mouvement d'air dans chacun des logements. Le passage de l'air autour de la porte d'entrée des appartements correspond à environ 40 p. 100 des fuites d'air totales du logement, les murs extérieurs et les fenêtres à 30 p. 100, les murs mitoyens à 20 p. 100 et les planchers à 10 p. 100.

Les mouvements d'air d'un appartement à l'autre sont surtout favorisés par les pénétrations pour canalisations de chauffage à eau chaude. Entre les étages, l'air passe principalement par les pénétrations aménagées dans le plancher des salles de bains pour les conduites de plomberie et dans les cuisines pour les câbles électriques.

L'installation de chauffage, de ventilation et de climatisation du bâtiment pressurise l'enveloppe de 2 à 7 Pa aux étages inférieurs et de 10 à 12 Pa aux étages supérieurs. Ces chiffres ont été déterminés par la prise d'une série de mesures des différences de pression au sein de l'enveloppe. Les lectures initiales ont été réalisées pendant le fonctionnement normal de l'installation puis ont été reprises alors que l'installation était arrêtée.

Le taux d'extraction total, par étage, des salles de bains ne représente que 25 p. 100 de l'admission d'air, par étage, provenant du corridor. Le reste de cet air en provenance du corridor est évacué à d'autres endroits, notamment par exfiltration à travers les murs extérieurs et les fenêtres, par les fuites dans la gaine d'ascenseur et les cages d'escalier ainsi que par les fuites intentionnelles causées par les bouches d'évacuation de sécheuse.

Quant à la qualité de l'air intérieur des deux bâtiments, les mesures du dioxyde de carbone, du monoxyde de carbone, du formaldéhyde et des colonies bactériennes sont toutes inférieures aux limites maximales fixées par Santé et Bien-être social Canada.

Le nombre de particules en suspension dans un logement du bâtiment A s'est avéré supérieur à ce que recommande Santé et Bien-être social Canada. Dans cinq des sept appartements étudiés dans le bâtiment B, les résultats excèdent considérablement la limite établie.

La plupart des occupants du bâtiment A, soit environ 80 p. 100, estiment que l'air est trop chaud et sec. L'humidité relative mesurée varie entre 12 et 27 p. 100 et la température de l'air mesurée se situe entre 25 et 30 °C.

La majorité des occupants du bâtiment B, soit environ 90 p. 100, jugent que l'air est trop chaud et sec. L'humidité relative mesurée varie entre 18 et 33 p. 100 et la température de l'air mesurée se situe entre 22 et 29 °C.

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1.0 INTRODUCTION

This field investigation survey was undertaken for Canada Mortgage and Housing Corporation. The overall objective was to establish to what extent building envelope, moisture, energy, comfort, and air quality problems exist in high-rise apartment buildings, using a sample of two such structures. These results will be used in part as a basis for establishing airtightness and air quality standards for apartment buildings.

The specific objectives of this investigation were as follows:

- Quantify suite airtightness of a representative group of suites.
- Establish the effect the HVAC system has on the pressure differential across the building envelope.
- Survey of building residents to establish the general environmental conditions.
- Monitoring of temperature and relative humidity, and the identification and quantification of five specific pollutants.
- Document the applicability of the procedures used with respect to future investigations and as candidate procedures for a standardized testing protocol.

This report was prepared by B.W. Gulay, P.Eng. and C.D. Stewart, P.Eng. of Wardrop Engineering Inc., G. Proskiw, P.Eng. of Unies Ltd., and P. Giesbrecht, P.Eng. of National Testing Laboratories Ltd. Access to the buildings was arranged by G. Darrach of Tuplin Group Inc.

2.0 BUILDING DESCRIPTIONS

2.1 GENERAL

The investigation was conducted on two 13-storey apartment buildings located in Winnipeg that are of nearly identical design, age, and occupancy. The buildings, identified as A and B, were constructed in 1973 and 1970 respectively.

Both buildings are double wythe brick and wood stud construction. The major difference between the two buildings is that in 1986, Building A was retrofitted with a torch applied air barrier membrane. Prior to the retrofit, Building A experienced classic air infiltration/exfiltration problems, as well as water leakage into the building. These problems resulted in severe damage to drywall surfaces, floor and ceiling finishes. These problems generated numerous occupant complaints. As a corrective measure, a thermal fusible membrane was applied to the exterior of the building, over the existing brick facade. New polyvinylchloride windows were installed and the building was then insulated with an additional 125 mm of semi-rigid fibreglass insulation and sheathed with aluminum siding. Building B remains essentially as originally constructed in 1970.

2.2 HVAC - BUILDING A

Building A is heated by means of low pressure hot water boilers located in the basement. Steam is supplied to perimeter radiation units in each suite. Temperature control is provided by wall-mounted thermostats located in each suite.

Ventilation air is not supplied to any of the suites directly. Outside air is brought in through an intake duct located about 2 meters above grade on the north side of the building. This air is heated and then supplied to each floor through a single supply air grille in each hallway. The design fresh air rate supply to each floor is 212 L/s. This air finds its way into the suites primarily through the 15 mm crack under each door.

This air is not mechanically cooled during the summer and many of the occupants complained about excessive temperatures through much of the year.

Mechanical cooling for the suites is provided by window-mounted air conditioners. Air conditioning is also supplied to the lounge and some other main floor spaces by means of a separate air handling/air conditioning system.

Air is exhausted from the washrooms of each suite through a vertical duct connected to a central exhaust fan. This fan system continuously exhausts air from the suites. There are two such systems in the building.

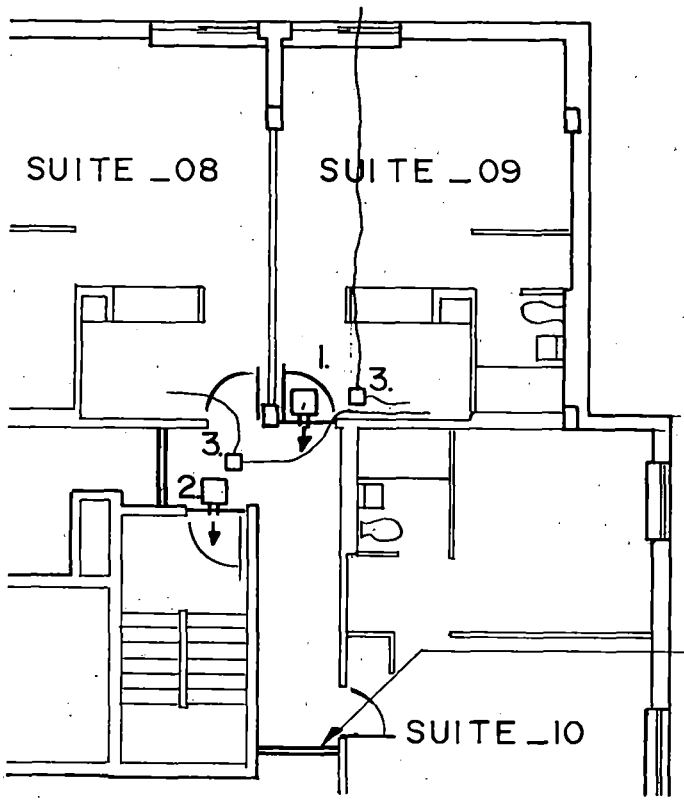
There is also a central exhaust fan system for the laundry rooms located on alternate floors that operates continuously.

2.3 HVAC - BUILDING B

Building B is also heated by means of low pressure steam boilers, with the boilers located on the main level. Steam is supplied to perimeter radiation units in each suite. Temperature control is provided by wall-mounted thermostats located in each suite.

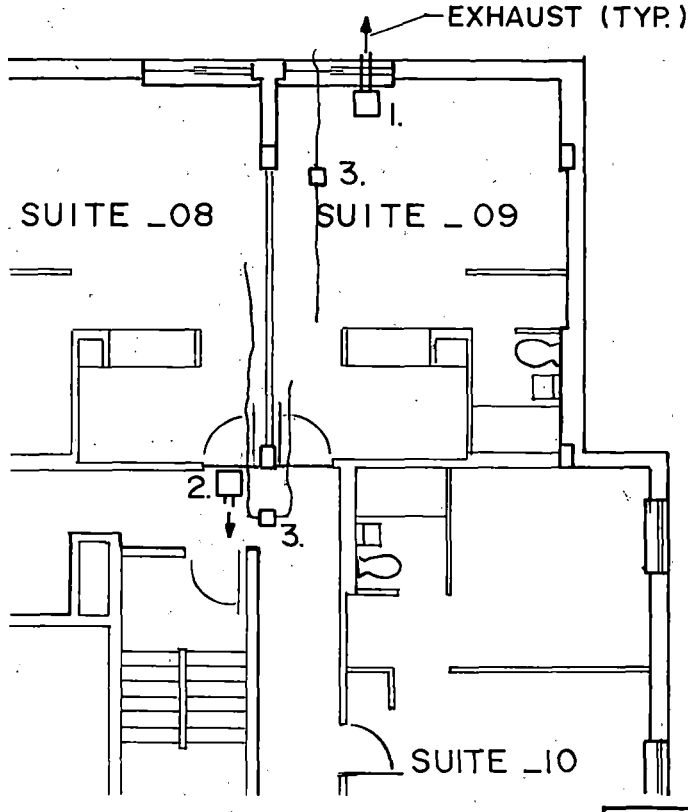
Ventilation air is not supplied to any of the suites directly. During the summer, fresh air is supplied to each floor through a single supply air grille located in the hallway. In the winter, the air is strictly recirculated air. In the summer, dampers on the make-up units are manually opened for ventilation to the hallways and to the common area lounge. The units are located in the storage room on the main floor, and only the unit for the lounge is cooled with city water. There are no provisions for air conditioning of the hallways or the individual suite.

The central exhaust fans for both the laundry and bathrooms are located on the roof and run continuously.



TEST CONDITION A

CORRIDOR BARRIER MASK (TYP.)
(6 mil POLY & 38x89 FRAMING)



TEST CONDITION B

LEGEND:

1. FAN WITH CALIBRATED NOZZLE.
2. PRESSURE BALANCING (MASKING) FAN
3. PRESSURE MEASURING DEVICE

CLIENT
CANADA MORTGAGE AND HOUSING CORPORATION

WARDROP ENGINEERING INC.
WINNIPEG TORONTO THUNDER BAY EDMONTON

DWG. DESCRIPTION
AIR LEAKAGE TEST EQUIP. LAYOUT WITH CORRIDOR BARRIER MASKS

DESIGNED BY	DRAWN BY K.B.B.	DRAWING NO.
CHECKED BY	DATE NOV. '91	910839-01-00-SK1

3.0 AIRTIGHTNESS AND AIR MOVEMENT

3.1 METHODOLOGY

The test protocol for suite airtightness and building envelope pressure differential measurements was based on "Establishing the Protocol for Measuring Air Leakage and Air Flow Patterns in High-Rise Apartment Buildings." The test protocol was modified as required to fit field conditions.

3.2 AIR LEAKAGE AND AIR FLOW PATTERNS

Three different airtightness test procedures were used to establish the six side air leakage of the subject suite. The first procedure, referred to as Condition A in the results, utilized a blower door assembly located and sealed into the entry door of the subject suite. A series of tests were then conducted with the subject suite and one or more adjacent suites depressurized to establish and quantify the air leakage rates through the six sides of the suite. As a part of the series, a "corridor barrier mask" was constructed in the hallway to allow for the simultaneous determination of the combined air leakage rates through the corridor, and the left and right partition walls. By combining the air leakage of this test with those obtained for floor to floor leakage, and subtracting from the total six-sided air leakage, it was possible to isolate the air leakage rate for the exterior wall. However, it should be noted that, while the air leakage rate was established for the exterior wall, the total six-sided excludes the leakage that would have occurred through the corridor door.

The second procedure, referred to in the results as Condition B, utilized a modified blower door assembly located and sealed into one of two small adjacent awning windows located in each suite. With this procedure, the six-sided air leakage recorded excludes the air leakage that would have occurred through this portion of the window. However, this procedure allowed for the calculation of the leakage through the corridor door by comparing two tests, one with the door sealed off, and one with the door unsealed.

The third procedure, referred to in the results as Condition C, was a variation of test condition A. For this test, the exterior window was sealed off with tape. This was done to calculate the leakage through the window from the total six-sided air leakage.

3.3 Envelope Pressure Differential Measurements

Measurements of typical building envelope pressure differentials were conducted under two configurations. This being with the hallway supply air ventilation system turned off, and again with it operating normally. In Building A, indoor-to-outdoor pressure differentials were measured across the windows in a total of nine suites located on six floors. In Building B, indoor-to-outdoor pressure differential readings were measured across the windows in a total of six suites located on six floors.

3.4 Hallway and Bathroom Air Supply and Exhaust Rates

Measurement of the hallway supply air and bathroom exhaust flow rates were also conducted. In Building A, the bathroom exhaust flow rates were measured in a total of nine suites on six floors. In Building B, the bathroom exhaust flow rates were measured in a total of seven suites on seven floors. The hallway supply air rates and temperatures for both buildings were measured on each floor, excluding the ground floor.

4.0 INDOOR AIR QUALITY

4.1 METHODOLOGY

The test protocol for indoor air quality monitoring was based on "Indoor Air Quality Test Protocol for High-Rise Residential Buildings."

4.1.1 Background

In the last decade, interest and concern relating to indoor air quality has heightened. This can often be linked to the construction of more tightly sealed buildings in the wake of the energy crisis of the early 1970s. These sealed structures are mainly dependent on a mechanical ventilation system for air supply and distribution.

Occupants of these structures are increasingly voicing a variety of non-specific health complaints and problems relating to the indoor environment. Typical symptoms of nasal, eye, and throat irritation, accompanied by headache, dry skin and lethargy, is commonly referred to as Sick Building Syndrome.

Various agencies, research groups and private consulting are now receiving frequent requests associated primarily with the indoor environment of buildings. Complaints are generally non-specific and the consultant is then faced with the difficult task of first deciding what to test for and secondly, to interpret the test results in a meaningful way.

4.1.2 General Approach

Indoor air quality in high-rise apartment buildings is often a complicated issue. In order to obtain useful information about the indoor air quality in high-rise apartment buildings, two areas must be examined. Firstly, an inspection of the building, identifying any factors that might contribute to indoor air quality problems, must be carried out.

Secondly, an Indoor Air Quality Survey distributed to the occupants of the building, is very important.

Based on the building inspection and the results of the survey, the appropriate indoor air quality testing program can then be developed.

4.1.3 Indoor Air Pollutants

There are literally hundreds of possible indoor air pollutants for which tests could be conducted. However, once the results from the survey are tabulated and interpreted, the appropriate test program and the number of relevant test parameters can be established.

No body of evidence could be found which described the types of indoor air pollutants which were likely present in high-rise apartments buildings. A literature review of pollutants commonly found in residences and public access buildings, however, can be summarized as follows:

- carbon dioxide
- carbon monoxide
- nitrogen dioxide
- radon
- ozone
- tobacco smoke
- particulates
- formaldehyde
- volatile organic compounds
- bacteria and mould

This is by no means a complete list but does include the most common indoor pollutants. Prior to testing, there was no evidence to suggest that the indoor air quality at

Buildings A and B was any better or any worse than other apartment buildings and neither building could, therefore, be described as "sick buildings".

It is worth noting that, even with sick buildings, air quality monitoring and testing has often proven to be a fruitless exercise, as concentrations of contaminants measured are often considered to be too low to have caused the illness complaints. It is distinctly possible that many of the illness complaints reported are the result of low-level exposure to a combination of pollutants.

4.1.4 Temperature and Humidity Levels

Dry bulb temperatures and relative humidity levels, although in themselves non-polluting, can be the cause of many of the health complaints commonly reported by building occupants. These include eye irritation, dry throat, fatigue, and skin irritation.

Relative humidity affects comfort; conditions of 20% to 80% relative humidity (depending on the time of year) and dry bulb temperatures between +20°C and +25°C are usually judged comfortable. Conditions outside of this region are generally considered uncomfortable and may make some people more susceptible to certain pollutants.

4.2 INDOOR AIR QUALITY SURVEY

4.2.1 Description

The survey form, consisting of 19 questions, is included in Appendix G. The most important elements in the survey relate to various conditions, such as temperature and humidity within each suite, as well as information on the health symptoms experienced by the occupants.

The results of the survey were intended to provide two useful things, namely:

1. Identification of suites with significant indoor air quality complaints that would be logical candidates for testing.

2. A means of determining which of the many indoor air quality parameters to test for.

4.2.2 Survey Distribution and Summary

Building A

The survey was distributed to all 120 suites and the occupants were asked to fill out the form as accurately and as quickly as possible and return the completed survey forms to the building manager. Within one week 89 forms, or about 75% of the total, were returned and formed the basis of the Summary of Indoor Air Quality Survey. The results of the survey are included in Appendix F.

The important information gathered from the survey form can be summarized as follows:

1. 92% are over 60 years of age.
2. 67% of the respondents spend more than 10 hours per day in the building.
3. 84% of the respondents do not smoke.
4. Only 26% had control over the humidity levels in their suites; almost all with portable vaporizers or humidifiers.
5. 83% felt there was a lack of air movement much of the time.
6. 90% felt the air was too dry.
7. There was no clear indication of how the respondents perceived the space temperatures, however, very few felt temperatures were too cold. A large majority (77%) felt temperatures were just right, while 55% often felt temperatures were too high. The anomaly in percentages is due to interpretation of the question by the respondents, some of them answering both ways.
8. The most common health complaints that respondents reported were dry skin (75%), fatigue (66%) and nose irritation 64%).
9. 45% of the respondents experienced relief when they were away from the building.

Building B

The survey was distributed to all 120 suites and the occupants were asked to respond as quickly and accurately as possible, and return the completed survey forms to the building superintendent.

Within the week, only 39 forms, or about 32% of the total were returned and formed the basis of the Summary of Indoor Air Quality Survey. The results of the survey are included in Appendix F. The important information gathered from the survey form can be summarized as follows:

1. 58% are over 60 years of age.
2. 84% of the respondents spend more than 10 hours per day in the building.
3. 76% of the respondents complained that the air was too dry.
4. 74% described the air as too stuffy.
5. 76% felt the temperature was too hot.
6. Common health complaints were fatigue, sleepiness, backache and skin dryness.

4.3 INDOOR AIR QUALITY MONITORING AND TESTING

4.3.1 Suite Selection

The survey forms were carefully examined to identify those suites that appeared to have the poorest indoor air quality. To assist in the suite selection process, discussions were also held with the building managers and caretakers to identify suites whose occupants had complained with more regularity about poor air quality.

The following suites were subsequently selected to participate in the indoor air quality monitoring and testing program.

BUILDING A		BUILDING B	
Suite No.	**Floor**	**Suite No.**	**Floor**
1404	13	1205	12
1204	12	1107	11
1104	11	1106	11
1004	10	803	8
606	6	702	7
503	5	610	6
209	2	403	4

The main floor lounges in both Buildings A and B were also included in some of the tests.

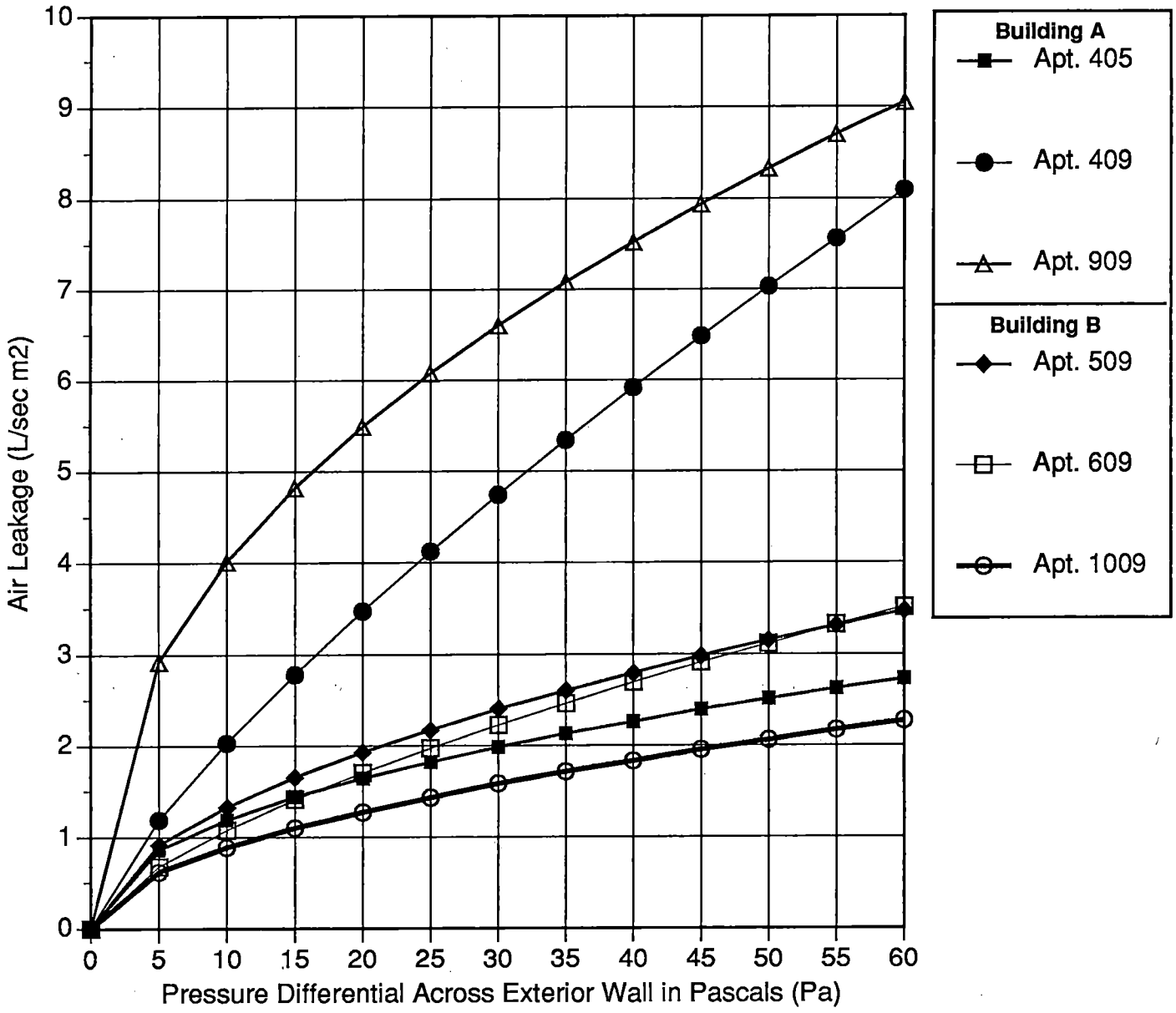
4.3.2 Test Parameters and Equipment

Shown below are the parameters that were finally selected, as well as the equipment used:

Parameter	Equipment
Temperature/Relative Humidity	Castella Londong T9420 Thermohygrograph
Carbon Dioxide	Horiba Model APBA-210
Carbon Monoxide	Ecolozer 4000 Series
Bacteriological	Agar Plates
Formaldehyde	PC-1 Monitors
Airborne Particulates	Vacuum Pump and Filter Disks

All equipment was calibrated before and after testing to ensure accuracy of the data.

Overall Airtightness of Exterior Wall



Note: Overall Air Leakage Rates for Building A Apartments 409 & 909 are for Combined Exterior Wall & Corridor Leakage

Figure 1

5.0 AIRTIGHTNESS AND AIR MOVEMENT RESULTS

5.1 OVERALL AIRTIGHTNESS OF EXTERIOR WALL

The overall air leakage rates per unit area of exterior wall for Buildings A and B are in the range of 2.06 to 3.15 L/sec.m^2 at a pressure differential of 50 Pa. By comparing the average of the three exterior wall leakage rates obtained for Building B with the sole similar test conducted for Building A, it was found that Building A was approximately 10% tighter than Building B. The exterior wall leakage rates are presented graphically on the page opposite.

The results from these tests indicate that Buildings A and B performed in a similar fashion to the buildings Shaw tested previously in Ottawa. His testing found leakage rates through the exterior wall of between 1.85 and 3.65 L/sec.m^2 at a pressure differential of 50 Pa. (NRC Report No. CR5855.1)

5.1.1 Airtightness Results - Suite #405 Building A

The measured airtightness of the exterior wall was 2.50 L/sec.m^2 at 50 Pa. This represented 42.7% and 24.7% of the total six-sided suite leakage for Conditions A and B, respectively. The corridor door accounted for 42.2% of the Condition B six-sided suite leakage.

5.1.2 Airtightness Results - Suite #409 Building A

As it was not possible to install the corridor barrier masks, the final airtightness results describe the combined air leakage across the exterior wall and the corridor partitions. The leakage rate was found to be 7.03 L/sec.m^2 at 50 Pa. This combined leakage represented 59.2% and 35.2%, of the total six-sided suite leakage for Conditions A and B, respectively. The corridor door accounted for 40.5% for the Condition B six-sided suite leakage.

5.1.3 Airtightness Results - Suite 909 Building A

Again, as it was not possible to install the corridor barrier masks, the final airtightness results describe the combined air leakage across the exterior wall and the corridor partitions. The leakage rate was found to be 8.33 L/sec.m^2 at 50 Pa. This combined leakage represented 56.6% and 31.9% of the total six-sided suite leakage for Conditions A and B, respectively. The corridor door accounted for 43.6% of the Condition B six-sided suite leakage.

5.1.4 Airtightness Results - Suite #509 Building B

The measured airtightness of the exterior wall was 3.15 L/sec.m^2 at 50 Pa. This represented 45.4% of the total six-sided Condition A suite leakage.

5.1.5 Airtightness Results - Suite #609 Building B

The measured airtightness of the exterior wall was 3.11 L/sec.m^2 (50 Pa). This represented 46.0% of the total six-sided Condition A suite leakage.

Ratio of Component Air Leakage to Overall Leakage For Individual Apartment Units, ΔP=50 Pa

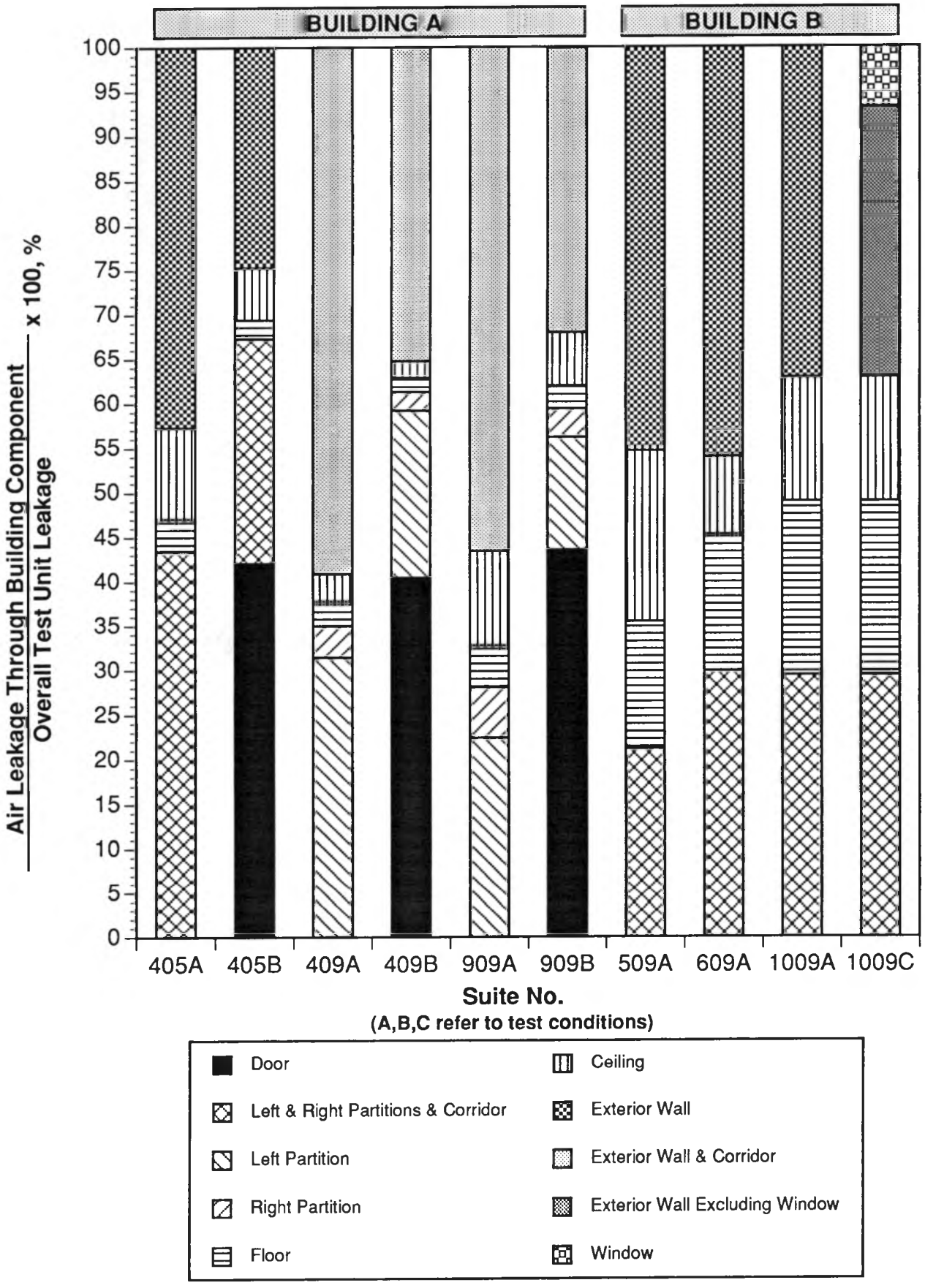


Figure 2

5.1.6 Airtightness Results - Suite #1009 Building B

The measured airtightness of the exterior wall was 2.10 L/sec.m^2 at 50 Pa. This represented 37.1% of the total six-sided Condition A suite leakage and 30.3% of the total six-sided Condition C suite leakage, if the window leakage is subtracted. The window accounted for 6.8% of the total six-sided suite leakage, or 18.6% of the total leakage through the exterior wall. This is significant as the window comprises 14.8% of the exterior window area. This implies that the exterior wall is of only marginally tighter construction than the window. In this case, the window being a 1.88 x 2.17 m double-pane sliding patio door.

5.2 DISTRIBUTION OF AIR LEAKAGE

The averaged six-sided air leakage rates for a corner suite in Buildings A and B was 287.3 L/s at 50 Pa. The average individual component leakage rates were as follows:

	L/s	Percentage of Total Six-Sided Leakage
Entry Door	119.4	41.5
Left and Right Partitions and Corridor	54.2	18.9
Floor	17.8	6.2
Ceiling	19.4	6.7
Exterior Wall Excluding Window	65.7	22.9
Window	10.8	3.8

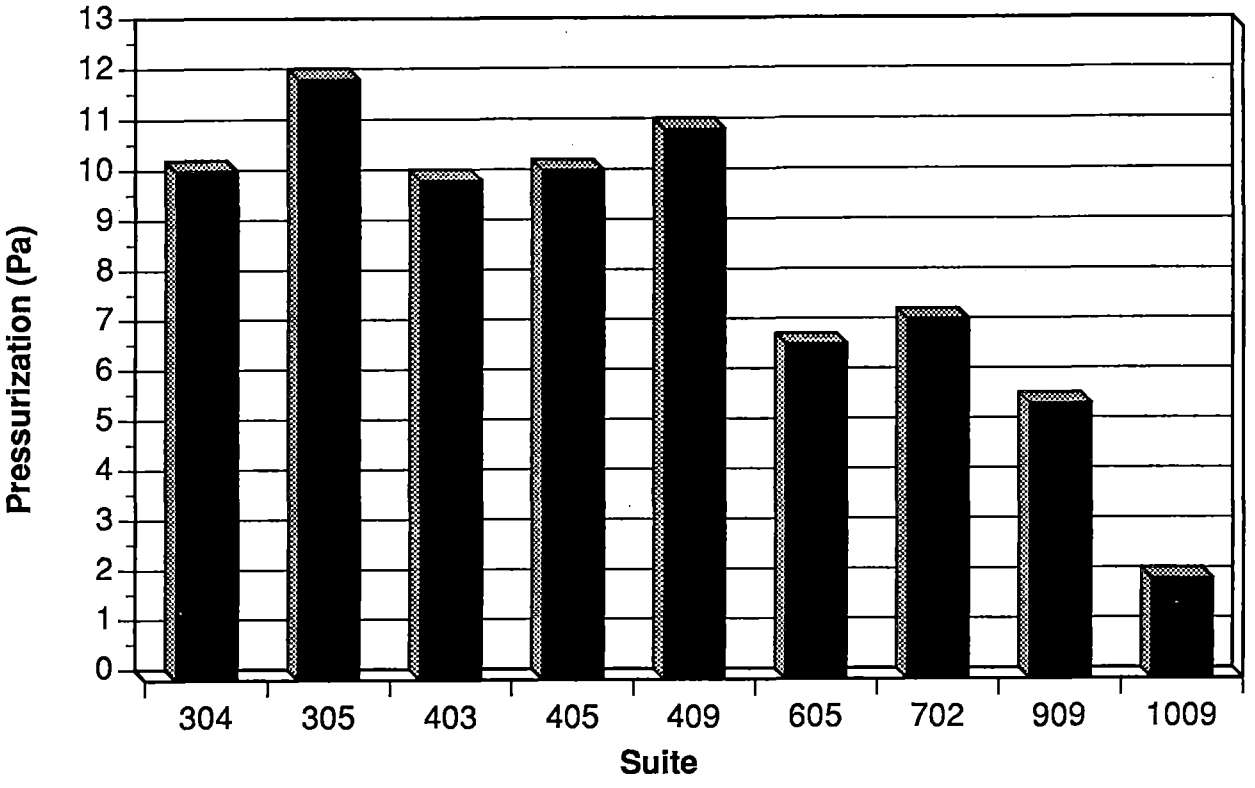
The largest single air leakage component was the suite entry door at 41.5% of the total six-sided leakage. While not unexpected, the magnitude of the door leakage should be noted, particularly since the testing procedure described by Shaw (circa 1990) does not include its determination. This large leakage rate can be attributed to the entry doors being deliberately undercut across the bottom to allow for the passage of supply air from the slightly pressurized hallway into the individual suites. This type of air flow should have little direct effect on the transportation of odours between adjacent suites, but would have substantial effect if the odour was present in the hallway.

The second largest leakage component was through the exterior wall. Where the suite is below the neutral pressure plane, the result is air infiltration. If the rate of infiltration is sufficient to compensate for the hallway pressurization, odours will migrate into the hallways. If the suite is above the neutral pressure plan, the leakage through the exterior wall is exfiltration. Again, this type of leakage will have little direct effect on the transmission of odours between suites.

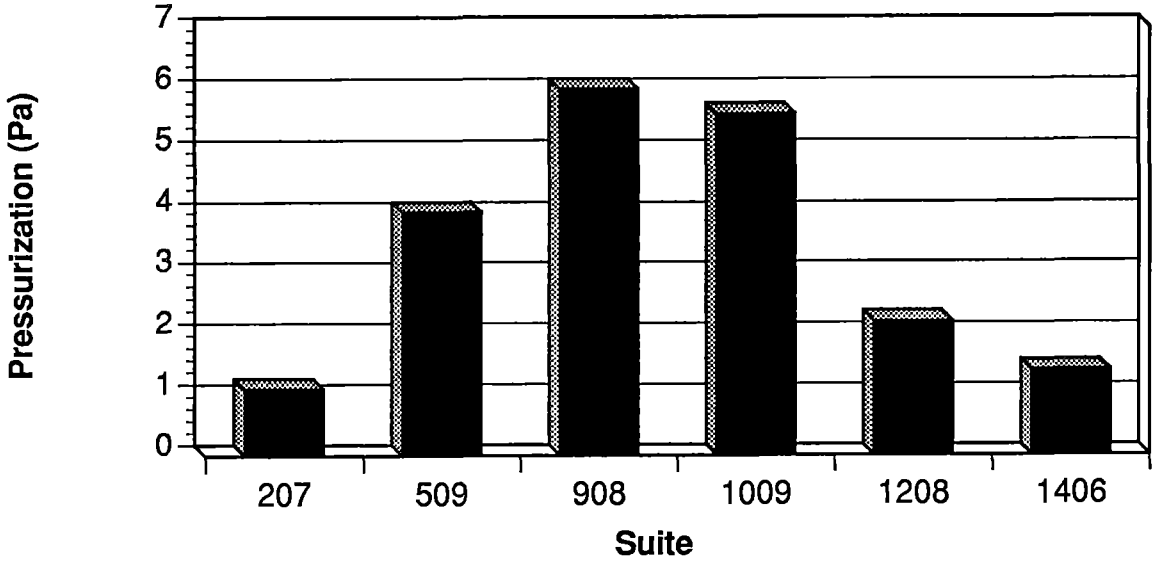
The leakage rates for the individual partition and corridor walls vary widely, but when averaged, each account for approximately 6.3% of the total leakage. This was essentially the same leakage rate found for the floors at 6.2%, and the ceilings at 6.7%. It is this direct type of suite to suite flow of air that is believed to be the major source of odour transmission within these apartment buildings.

The major leakage paths between floors was through the plumbing wall in the bathroom, and open electrical conduits in the kitchen. The major leakage paths through the partition walls was through hydronic heating line penetrations, electrical receptacles, and the space at the top and bottom of these walls.

Building Envelope Pressurization Caused By Mechanical Supply Air System



BUILDING A



BUILDING B

Figure 3 & 4

5.3 BUILDING ENVELOPE PRESSURE DIFFERENTIAL RESULTS

The building envelope pressurization created by the mechanical ventilation system in Buildings A and B are shown on the attached Figures 3 to 6. In general, the ventilation system pressurized the building envelope by 4 to 12 Pa on the lower floors, and by 2 to 7 Pa on the upper floors. Variations in the upper and lower floor pressurization are believed to have been caused by tenants on upper floors keeping their windows slightly open at the time of testing. The tenants are instructed by the building owner to keep their windows closed during the winter heating season, but this rule is not always observed.

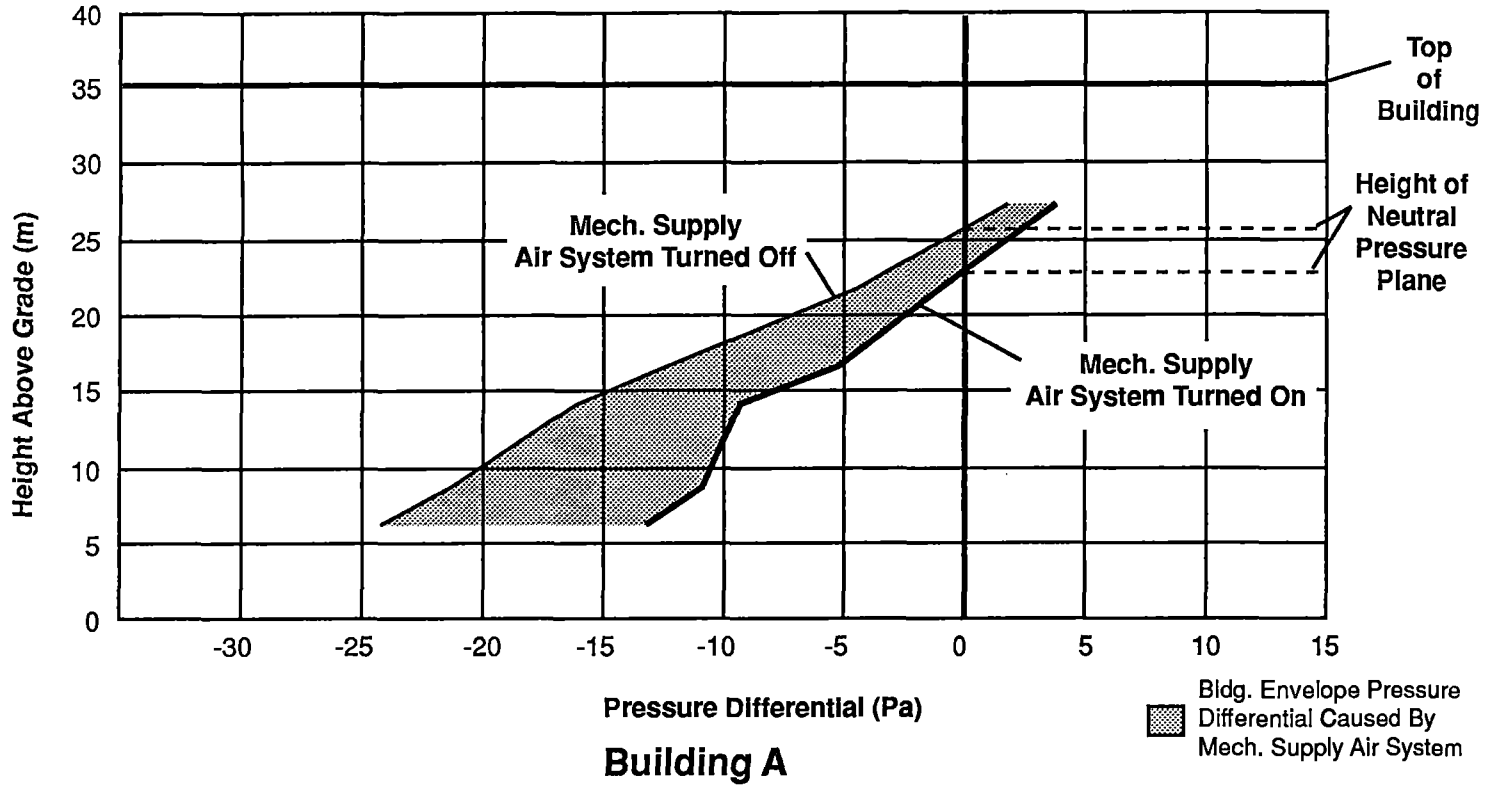
The magnitude of mechanical pressurization found has two important influences on these buildings. The first is to lower the height of the neutral pressure plan, see page following. This results in an increased area of the building envelope being subjected to positive internal pressurization. The second is to increase the magnitude of pressurization across the building envelope. These two conditions combined could greatly increase the moisture transportation and deposition through the building envelope.

5.4 HALLWAY AND BATHROOM AIR SUPPLY AND EXHAUST RATES

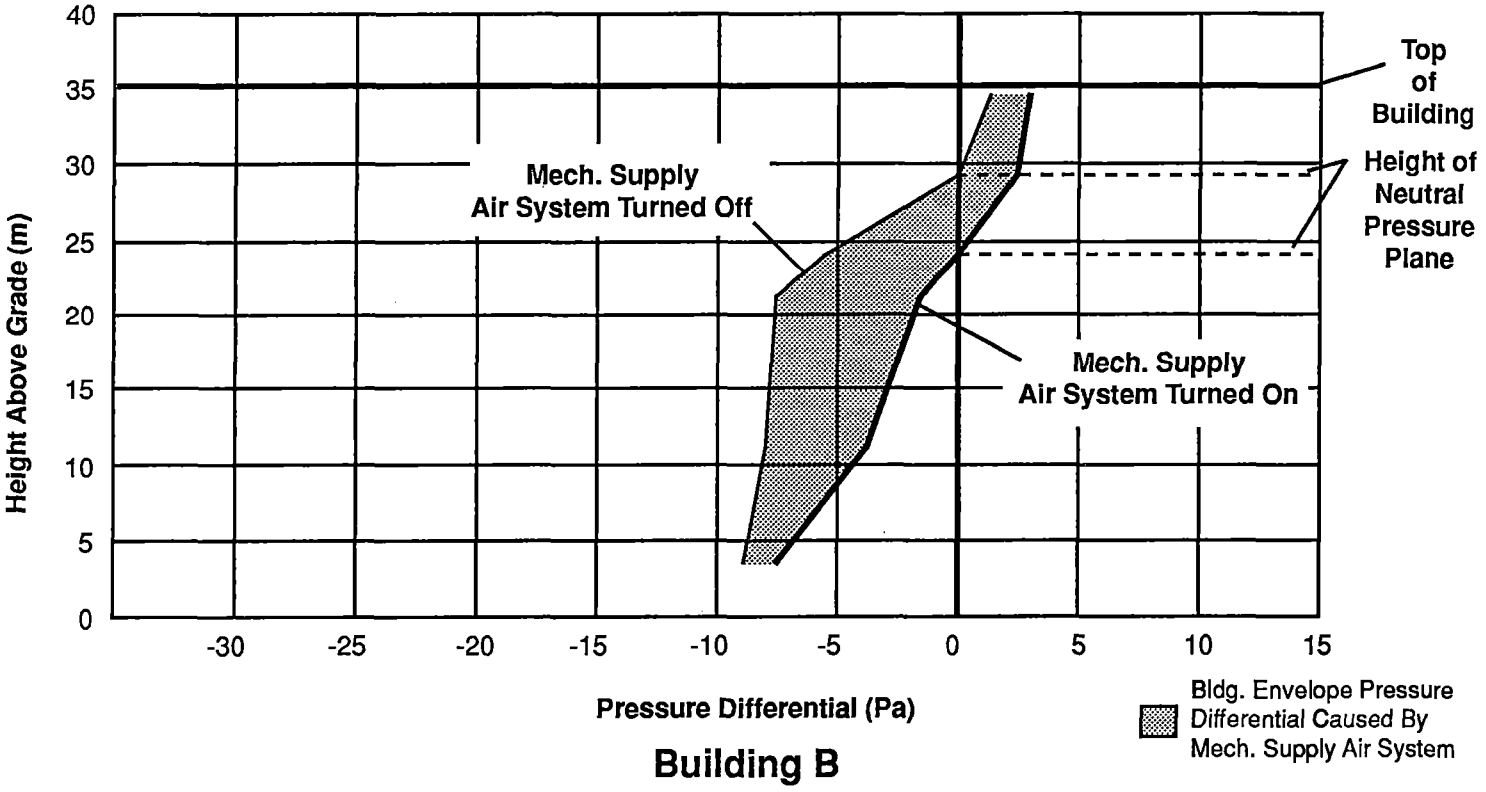
Ventilation supply air flow rates in both buildings were also measured on each floor and were found to be reasonably similar on those floors on which the exhaust flow rates were measured.

In Building A, the average measured supply air flow rate was 268 L/s per floor. This exceeded the design supply air flow rate of 212 L/s by approximately 25%. However, the total air flow to the individual suites was substantially less than the supply air rate. Using the measured average bathroom exhaust floor rate of 6.8 L/s, and multiplying by 10 suites per floor, gives a total exhaust flow rate of 68 L/s per floor. This was approximately 25% of the supply air flow rate.

Building Envelope Pressure Differential Measurements



Building A



Building B

Figure 5 & 6

The air flow through the elevator shafts was measured in the penthouse at Building A, and was found to be 1300 L/s, or approximately 100 L/s per floor. The remaining amount, 100 L/s per floor, was exhausted through other locations, including air exfiltration through the exterior walls and windows, plus leakage through the stair shafts, and that which was intentionally exhausted by the laundry dryer vents.

In Building B, the average measured supply air flow rate was 390 L/s per floor. This exceeded the design supply air flow rate of 212 L/s by approximately 84%. The total air flow to the individual suites was again substantially less than the supply air rate. Using the measured average bathroom exhaust flow rate of 8.1 L/s, and multiplying by 10 suites per floor, gives a total exhaust flow rate of 81 L/s per floor. This is approximately 21% of the design supply air flow rate.

The remaining 309 L/s per floor was exhausted through other locations, including air exfiltration through the exterior walls and windows, plus leakage through the elevator and stair shafts, and that which was intentionally exhausted by the laundry dryer vents.

6.0 AIR QUALITY TEST RESULTS

Testing at Building A was conducted during the period from February 20-27, 1991, while testing at Building B was conducted during the period from March 8-18, 1991. Depending on the type of test, the equipment was installed in the suites from 2 hours to 7 days. The equipment was set up in a central location in each suite and occupants were instructed not to tamper with the equipment or alter their normal schedule. All occupants cooperated fully during the testing period.

6.1 SPACE TEMPERATURES

Mean space temperatures in the suites of Building A ranged from a high of +29.2°C (Suite 1004) to a low or +25.6°C (Suite 209). The maximum recorded temperature was +30.5°C and the lowest was +25.5°C. Temperatures in the lounge were generally lower than in the suite.

Mean space temperatures in the suites of Building B ranged from a high of +28.5°C (Suite 803) to a low of +22.3°C (Suite 610). The maximum recorded temperature was +28.8°C and the lowest was +21.7°C. Temperatures in the lounge were also generally lower than in the suites.

A summary of the space temperatures for both buildings is included in Appendix D, Table 2.

6.2 RELATIVE HUMIDITIES

Mean relative humidities in the suites of Building A ranged from about 12% to 27%. The maximum value recorded was 33% and the lowest was 9%.

Mean relative humidities in the suites of Building B ranged from about 18% to 33%. The maximum value recorded was 35.5% and the lowest was 14.4%.

The majority of people recognize relative humidity levels ranging from 30% to 80% - summer, and 30% to 55% - winter, as being acceptable. The mean humidity levels at Building A generally fall below 30%, indicative of a dry environment. At Building B, the mean humidity levels also fall below 30%, also indicating a dry environment.

The combination of dry bulb temperatures and corresponding relative humidity levels can be plotted on a psychometric chart to see whether these values fall within ASHRAE Comfort Standard 55-74. Seven out of eight locations tested in Building A fall outside the comfort zone, confirming a warm, dry environment. All eight locations tested at Building B fall outside the comfort zone.

The results of the relative humidity testing (Tables 3 and 4), and the psychometric charts (Figures 1 and 2) for both buildings are included in Appendix D.

6.3 CARBON DIOXIDE (CO_2)

Carbon dioxide is often used as the primary indicator of inadequate ventilation air in buildings. Studies suggest that CO_2 concentrations above 1,800 mg/m^3 (1,000 ppm) are indicative of an inadequate supply of fresh air, although complaints have been documented at concentrations as low as 1,080 mg/m^3 (600 ppm).

Mean CO_2 values measured in Building A ranged from 400 to 1,190 mg/m^3 (220 to 660 ppm). The levels of CO_2 are well below the action level range, indicating an adequate outside air supply.

Mean CO_2 values measured in Building B ranged from 970 to 1,730 mg/m^3 (540 to 960 ppm). The CO_2 levels measured in four suites of Building B are close to the action level of 1,800 mg/m^3 (1,000 ppm), usually indicative of an inadequate outside air supply.

Tables 5 and 6 in Appendix D summarize the results of the CO_2 monitoring in both buildings.

6.4 Carbon Monoxide (CO)

It was suspected that the major source of carbon monoxide was vehicle exhaust. Due to the proximity of a parking area near the main outside air intakes of both buildings, it was felt that some of the vehicle exhaust could be drawn into the buildings and distributed to the suites.

Mean CO values measured in Building A ranged from 0 to 2.0 mg/m^3 (0 to 1.1 ppm). Acceptable short-term exposure limit in residential air for CO is less than 20 mg/m^3 (11 ppm). Typical indoor CO concentrations in residences have been found to be vary from 0.9 to 9.0 mg/m^3 (0.5 to 5 ppm). CO readings at Building A are at the low end of this range.

Mean CO values measured in Building B ranged from 0.9 to 13.1 mg/m^3 (0.5 to 7.3 ppm). All CO readings at Building B are less than the acceptable limit 20 mg/m^3 (11 ppm).

The results of CO monitoring are summarized in Tables 7 and 8, Appendix D.

6.5 BACTERIOLOGICAL TESTING

Bacterial colony counts for both Buildings A and B range from less than 1 to a maximum of 105 and only one suite, number 503 in Building A, exhibited any evidence of mould. Workplace health officials in Manitoba consider anything less than 300 bacteria colonies to be acceptable and both buildings show values much less than this. No published acceptable limits for mould growth were found.

6.6 FORMALDEHYDE

Formaldehyde is a potent eye, upper respiratory and skin irritant, and these health complaints were described by a large percentage of the occupants of both apartments. Formaldehyde is usually associated with particleboard, new carpeting, etc. and, although little change had been made to the interiors of these buildings, formaldehyde monitors were placed in one randomly selected suite in each apartment.

The formaldehyde concentrations for both suites were found to be less than 0.1 mg/m^3 (/ 0.006 ppm). The Canadian exposure guideline for acceptability of residential indoor air with respect to formaldehyde is 0.18 mg/m^3 (0.1 ppm).

The results of the formaldehyde testing are summarized in Table 10, Appendix D.

6.7 AIRBORNE PARTICULATES

Airborne particulates, sometimes called house dust, consists of a variety of substances, including cotton, wool, and other fabrics, dyes from materials, food particles, hairs, dead skin cells and decomposed material.

Airborne particles are notable because they have been known to cause allergies and asthma, and are suspected to cause symptoms associated with sick building syndrome.

The concentration of airborne particulates in Building A ranged from less than 31 ug/m^3 to as high as 456 ug/m^3. Health and Welfare Canada uses a value of 40 ug/m^3 as the Acceptable Short-Term Exposure Range (ALTER)[1*]. The airborne particulates at Building A are considerably higher than this value.

The concentration of airborne particulates in Building B ranged from less than 833 ug/m^3 to 32,500 ug/m^3. All measurements greatly exceed Health and Welfare standards.

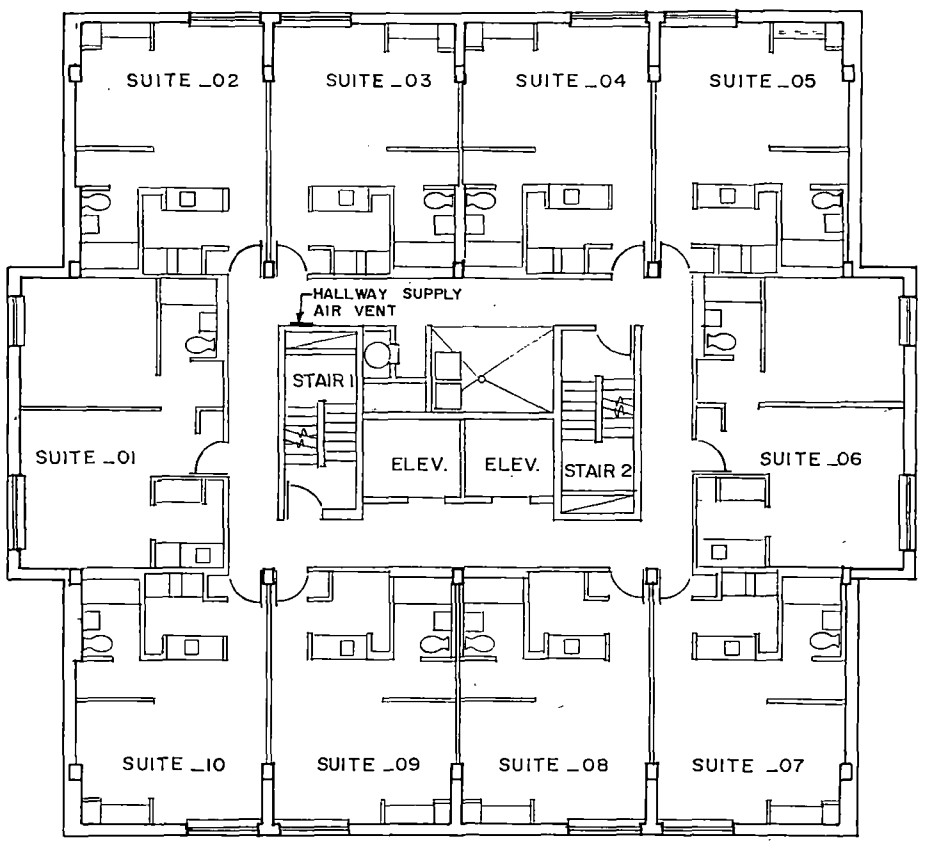
The results of airborne particulates for both buildings are included in Tables 11 and 12, Appendix D.

7.0 CORRECTIVE ACTIONS

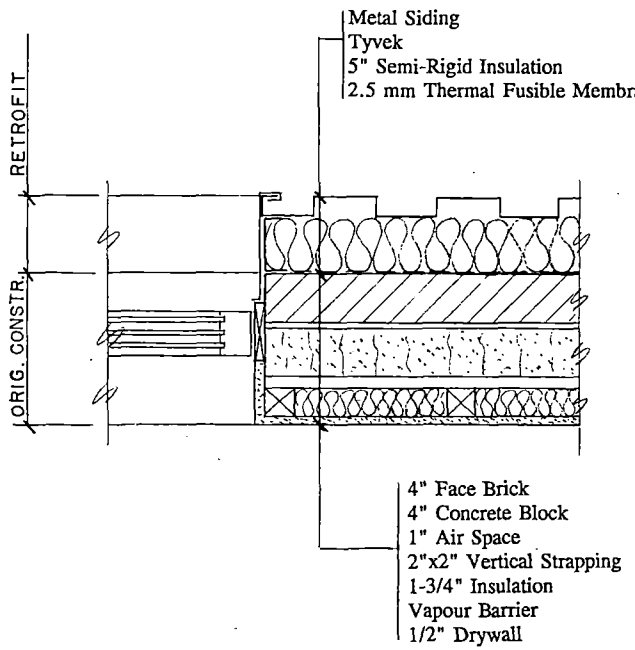
In conjunction with the building owners, corrective actions are being determined to reduce the carbon dioxide and airborne particulate levels in both buildings.

After implementation of these corrective actions, additional testing will be conducted to confirm their success.

APPENDIX A
TYPICAL FLOOR PLANS AND WALL SECTIONS



TYPICAL FLOOR PLAN (3 TO 14 INCLUSIVE)



TYPICAL WALL CONSTRUCTION

NO.	DESCRIPTION	DATE	BY
	REVISIONS / ISSUE		

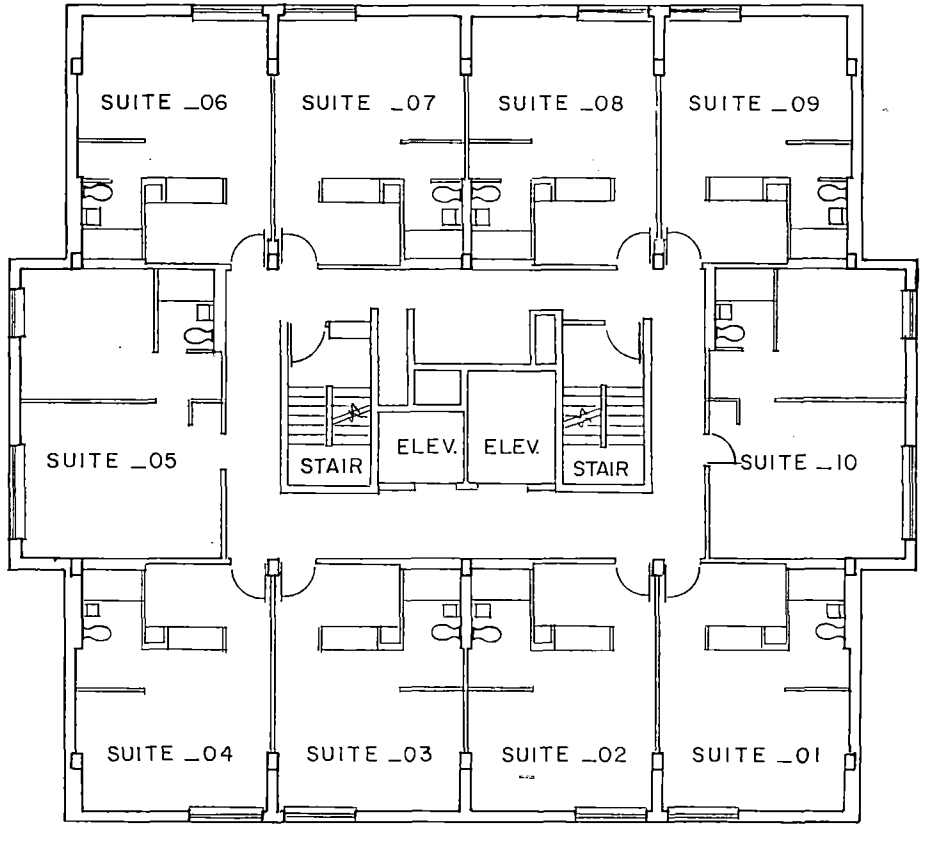
WARDROP ENGINEERING INC.

CLIENT: CANADA MORTGAGE AND HOUSING CORPORATION

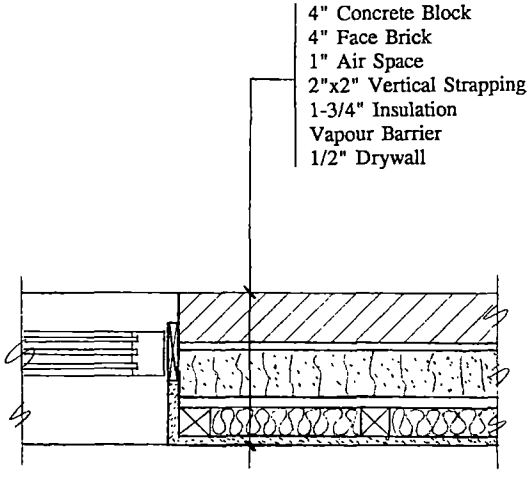
DWG. DESCRIPTION: BUILDING A
AIR LEAKAGE MONITORING

DESIGNED BY:	DRAWN BY: T. O.	DWG NO.
CHECKED BY:	DATE: MARCH '91	910839-01-00-SK2

W5024-(09/87)



TYPICAL FLOOR PLAN (2 TO 12 INCLUSIVE)



TYPICAL WALL CONSTRUCTION

NO.	DESCRIPTION	DATE	BY
	REVISIONS/ISSUE		

WARDROP ENGINEERING INC.

CLIENT: CANADA MORTGAGE AND HOUSING CORPORATION

DWG. DESCRIPTION: BUILDING B
AIR LEAKAGE MONITORING

DESIGNED BY:	DRAWN BY: T.O.	DWG NO.
CHECKED BY:	DATE: APRIL 91	910839-01-00-SK3

W5024-(09/87)

APPENDIX B
DETAILED TEST PROCEDURES

DETAILED TEST PROCEDURE FOR MEASURING AIR LEAKAGE AND AIR FLOW PATTERNS IN HIGH-RISE APARTMENT BUILDINGS

TEST CONDITION A: **Blower Door Assembly Located in Entry Door to Subject Suite**

Test No. 1: **Total Six-Sided Air Leakage (No Pressure Masking)**

Test Set-Up

- Tightly close all windows.
- Open all interior doors.
- Seal off window air conditioners.
- Seal all supply air or exhaust vents.
- Open stair shaft doors on floor of suite being tested and on floors two levels above and below.
- Install pressure tap to the exterior, through the living room window (tap must point upwards or downwards).
- Install and seal blower in the centre of test suite as the reference pressure point.
- Connect the pressure tap from the exterior wall and one of the reference pressure taps to a digital manometer, connect the pressure tap from the calibrated nozzle, and the second reference pressure tap to a second digital manometer (keep the manometers out of all air drafts as they are sensitive to temperature changes).

Test Procedure

- Record test date and time.
- Measure and record:
  - outdoor air temperature
  - indoor air temperature
  - wind speed and direction
  - initial ambient atmospheric pressure
- Zero all manometers.
- With fan turned off and inlet nozzle sealed off, record initial base pressure differential across the exterior wall.
- Remove seal from inlet nozzle and turn fan off.
- Adjust flow rate of fan in subject suite until the pressure differential across the exterior wall is 50 Pa above the baseline pressure measured.
- Allow pressures and flows to stabilize.

. Record all pressures.
. Record air temperature at inlet nozzle of fan.
. Repeat the procedure varying indoor to outdoor pressure differentials from 50 15 Pa, in decreasing increments of approximately 3 Pa.
. Turn fan off and seal inlet nozzle, record final base pressure differential across the exterior wall (if substantial discrepancies exist between initial and final baseline pressure differentials, discard test results).

Test No. 2: **Exterior, Floor and Ceiling Leakage (Pressure Masks Built in Corridor)**

Test Set-Up

. Repeat set-up as per Test No. 1, in addition:

. Build pressure masks in corridor to encompass subject suite and suites immediately to the left and right of the subject suites.
. Open entry doors of left and right hand suites.
. Open all interior doors of left and right hand suites.
. Close windows of left and right hand suites.
. Install pressure tap in centre of corridor, located away from the influence of the pressurization fans.
. Install second blower door in stair shaft doorway (fan exhausting into stair shaft).
. Connect the pressure taps from the subject suite and the corridor to a digital manometer located in the hallway.

Test Procedure

. Record test date and time.
. Measure and record:
  - outdoor air temperature
  - indoor air temperature
  - wind speed and direction
  - initial ambient atmospheric pressure
. Zero all manometers.
. With all fans turned off and the subject suite fan inlet nozzle sealed off, record initial base pressure differential across the exterior wall.
. Remove seal from inlet nozzle and turn subject suite fan on.
. Adjust flow rate of fan in subject suite until the pressure differential across the exterior wall is 50 Pa above the baseline pressure measured.

- Allow pressures and flows to stabilize.
- Record all pressures.
- Record air temperature at inlet nozzle of fan.
- Repeat the procedure varying indoor to outdoor pressure differentials from 50 and 15 Pa, in decreasing increments of approximately 3 Pa.
- Turn all fans off and seal inlet nozzle, record final base pressure differential across the exterior wall (if substantial discrepancies exist between initial and final baseline pressure differentials, discard test results).

Test No. 3-6: **Five-Sided Air Leakage (One Adjacent Suite Masked Off)**

Test Set-Up

- Repeat set-up as per Test No. 1, in addition, perform the following on one of the adjacent suites:

- Install a pressure tap from the centre of the room into the hallway.
- Tightly close all windows.
- Install a blower door assembly in the entry door (fan assembly to exhaust into the corridor).
- Install a pressure tap from the centre of the subject suite to the doorway of the adjacent suite.
- Connect the pressure taps from the subject and adjacent suites to a manometer located in the hallway.

Test Procedure

- Repeat procedure from Test No. 2.
- Repeat this test with the second blower door located in the doorway of one of the suites immediately above, below, to the right, or left of the subject suite.

Note: This procedure can be used to mask out the suites above and below the subject suite only if the partition walls of these suites align with the partition walls of the subject suite.

TEST CONDITION B: Blower Door Assembly Located in Window of Subject Suite to Determine Leakage Through Entry Door

Test Set-Up and Procedure

. Repeat set-up and procedure as per Test No. 1, with the exception of the blower door location, in addition:

. Perform the test with the entry door closed normally, and a second time with the entry door closed and sealed.

TEST CONDITION C: Blower Door Assembly Located in Entry Door of Subject Suite to Determine Leakage Through the Exterior Window

Test Set-Up and Procedure

. Repeat set-up and procedure as per Test No. 1.
. Perform the test with the windows closed normally, and a second time with the windows closed and sealed off.

APPENDIX C
AIRTIGHTNESS AND AIR MOVEMENT DATA COLLECTED

NOMENCLATURE

Pex = Indoor–to–outdoor pressure differential (Pa)
P b/d = Pressure differential across blower door (Pa)
Q6 = Six–sided leakage (l/s)
Qc = Ceiling leakage (l/s)
Qf = Floor leakage (l/s)
Ql,r,cor = Left and right partition and corridor leakage (l/s)
Qrem = Q6 – Qc – Qf – Ql,r,cor

WORKSHEET FOR CALCULATING THE REGRESSION EQN. OF A PARTITION USING THE DIFFERENCE BETWEEN TWO AIRTIGHTNESS TESTS.

BUILDING: A

TEST SUITE: 405

LEAKAGE CALCULATED: EXTERIOR WALL

EXTERIOR WALL AREA: 28.32 m2

ANALYSIS:

Q6 – NO PRESSURE MASKING
C = 19.9574
n = 0.5374

Airtightness test results for the Test Suite without simultaneous depressurization of adjacent suites.

*Suite orientations as viewed from corridor looking into suite.

TOP SUITE PRESSURE MASKED
C = 18.0237
n = 0.5359

Airtightness test results for the Test Suite with simultaneous depressurization.

LEFT & RIGHT SUITES & CORRIDOR PRESSURE MASKED
C = 12.1659
n = 0.5163

BOTTOM SUITE PRESSURE MASKED
C = 21.0668
n = 0.5169

Pex	P b/d	Q6	Qc	Qf	Ql,r,cor	Qrem	ln(P ex)	ln(Qrem)
49	48	161.59	16.51	4.10	70.85	70.14	3.891820	4.250423
41	43	146.83	14.96	3.20	64.07	64.60	3.713572	4.168189
39	41	142.94	14.56	2.97	62.28	63.12	3.663561	4.145092
36	38	136.92	13.93	2.63	59.53	60.83	3.583518	4.108104
34	34	132.78	13.50	2.39	57.64	59.24	3.526360	4.081675
33	33	130.66	13.28	2.28	56.68	58.43	3.496507	4.067866
31	31	126.35	12.83	2.04	54.71	56.77	3.433987	4.038935
29	29	121.90	12.37	1.81	52.69	55.04	3.367295	4.008055
25	28	112.55	11.40	1.33	48.45	51.38	3.218875	3.939270
22	24	105.08	10.62	0.97	45.07	48.42	3.091042	3.879956
21	23	102.49	10.35	0.85	43.90	47.39	3.044522	3.858355
20	21	99.83	10.08	0.73	42.70	46.33	2.995732	3.835691
16	19	88.55	8.91	0.24	37.64	41.76	2.772588	3.731920
16	18	88.55	8.91	0.24	37.64	41.76	2.772588	3.731920

ln(P b/d)	ln(Qc)	ln(Qf)	ln(Ql,r,c)
3.871201	2.803732	1.410361	4.2605880
3.761200	2.705589	1.162923	4.1599599
3.713572	2.678052	1.088903	4.1317196
3.637586	2.633977	0.965366	4.0865135
3.526360	2.602503	0.872813	4.0542266

3.496507	2.586064	0.822856	4.0373620
3.433987	2.551636	0.714198	4.0020388
3.367295	2.514911	0.591427	3.9643533
3.332204	2.433175	0.285311	3.8804635
3.178053	2.362774	-0.03108	3.8081855
3.135494	2.337153	-0.16419	3.7818771
3.044522	2.310282	-0.31808	3.7542816
2.944438	2.187378	-1.41767	3.6280305
2.890371	2.187378	-1.41767	3.6280305

REGRESSION EQUATIONS:

EXTERIOR WALL

Regression Output:

Constant		2.447331	
Std Err of Y Est		0.000234	
R Squared		0.999998	r = 0.9999990
No. of Observations		14	
Degrees of Freedom		12	
X Coefficient(s)	0.463429		
Std Err of Coef.	0.000185		

Regression equations to calculate the leakage characteristics of the exterior wall, ceiling, floor, and (combined) left and right partitions plus the corridor wall.

REGRESSION EQUATION DESCRIBING EXTERIOR WALL LEAKAGE:

C = 11.55746

n = 0.463429

CEILING

Regression Output:

Constant		0.397435	
Std Err of Y Est		0.023416	
R Squared		0.986446	r = 0.9931999
No. of Observations		14	
Degrees of Freedom		12	
X Coefficient(s)	0.619665		
Std Err of Coef.	0.020968		

REGRESSION EQUATION DESCRIBING CEILING LEAKAGE:

C = 1.488004

n = 0.619665

FLOOR

Regression Output:

Constant		-9.02564	
Std Err of Y Est		0.282485	
R Squared		0.908795	r = 0.9533078
No. of Observations		14	
Degrees of Freedom		12	
X Coefficient(s)	2.766041		
Std Err of Coef.	0.252954		

REGRESSION EQUATION DESCRIBING FLOOR LEAKAGE:

C = 0.000120

n = 2.766041

LEFT, RIGHT, PARTITION CORRIDORS

Regression Output:

Constant		1.791010	
Std Err of Y Est		0.024055	
R Squared		0.986420	r = 0.9931872
No. of Observations		14	
Degrees of Freedom		12	
X Coefficient(s)	0.635996		
Std Err of Coef.	0.021541		

REGRESSION EQUATION DESCRIBING LEFT, RIGHT, CORR. LEAKAGE:

C = 5.995508

n = 0.635996

RESULTS: AIR LEAKAGE RATES @ 50 Pa

CONDITION A: 6-SIDED LEAKAGE IGNORING DOOR

	LEAKAGE l/s	PERCENTAGE DISTRIBUTION
L & R PART. & CORR.	72.17	43.5 %
FLOOR	6.02	3.6 %
CEILING	16.80	10.1 %
EXTERIOR WALL	70.83	42.7 %
TOTAL	165.82 l/s	100.00 %

EXTERIOR WALL LEAKAGE PER SQUARE METRE OF EXTERIOR WALL: 2.50 l/s m2

CONDITION B: 6-SIDED LEAKAGE IGNORING WINDOW

	LEAKAGE l/s	PERCENTAGE DISTRIBUTION
DOOR	120.94	42.2 %
L & R PART. & CORR.	72.17	25.2 %
FLOOR	6.02	2.1 %
CEILING	16.80	5.9 %
EXTERIOR WALL	70.83	24.7 %
TOTAL	286.76 l/s	100.00 %

EXTERIOR WALL LEAKAGE PER SQUARE METRE OF EXTERIOR WALL: 2.50 l/s m2

WORKSHEET FOR CALCULATING THE REGRESSION EQN. OF A PARTITION USING THE DIFFERENCE BETWEEN TWO AIRTIGHTNESS TESTS.

BUILDING: A

TEST SUITE: 409

LEAKAGE CALCULATED: EXTERIOR WALL AND CORRIDOR

EXTERIOR WALL AREA: 12.17 m2

ANALYSIS:

Q6 – NO PRESSURE MASKING
C = 15.1435
n = 0.5740

Airtightness test results for the Test Suite without simultaneous depressurization of adjacent suites.

*Suite orientations as viewed from corridor looking into suite.

TOP SUITE PRESSURE MASKED
C = 10.7899
n = 0.6522

Airtightness test results for the Test Suite with simultaneous depressurization.

LEFT SUITE PRESSURE MASKED
C = 12.8594
n = 0.5226

RIGHT SUITE PRESSURE MASKED
C = 12.6294
n = 0.6109

BOTTOM SUITE PRESSURE MASKED
C = 12.7282
n = 0.6112

Pex	P b/d	Q6	Qc	Qr	Qf	Ql	Qrem	ln(P ex)	ln(Qrem)
57	54	154.20	3.48	4.91	3.56	47.83	94.43	4.043051	4.547876
55	52	151.08	3.82	5.00	3.68	46.67	91.91	4.007333	4.520769
52	49	146.29	4.32	5.14	3.86	44.90	88.07	3.951243	4.478158
48	46	139.72	4.97	5.30	4.09	42.48	82.87	3.871201	4.417255
48	44	139.72	4.97	5.30	4.09	42.48	82.87	3.871201	4.417255
39	38	124.02	6.34	5.62	4.56	36.78	70.72	3.663561	4.258734
36	33	118.45	6.76	5.70	4.70	34.79	66.51	3.583518	4.197414
30	29	106.68	7.51	5.81	4.92	30.62	57.82	3.401197	4.057284
26	25	98.27	7.93	5.84	5.03	27.69	51.77	3.258096	3.946838
24	23	93.86	8.12	5.84	5.07	26.17	48.66	3.178053	3.884879
18	17	79.57	8.50	5.74	5.10	21.33	38.90	2.890371	3.661064
15	14	71.66	8.56	5.62	5.05	18.72	33.73	2.708050	3.518262

ln(P b/d)	ln(Qc)	ln(Qr)	ln(Qf)	ln(Ql)
3.988984	1.245661	1.591173	1.269467	3.8676460
3.951243	1.339360	1.609943	1.303647	3.8430485
3.891820	1.463198	1.636368	1.351577	3.8043729
3.828641	1.603793	1.668352	1.409635	3.7490744
3.784189	1.603793	1.668352	1.409635	3.7490744
3.637586	1.846828	1.726016	1.517483	3.6050229
3.496507	1.910480	1.740371	1.546532	3.5492523

3.367295	2.016116	1.760276	1.593545	3.4216949
3.218875	2.071100	1.765569	1.615572	3.3210471
3.135494	2.093795	1.765206	1.623267	3.2645383
2.833213	2.139755	1.747688	1.629084	3.0601131
2.639057	2.147007	1.725742	1.618575	2.9294160

REGRESSION EQUATIONS:

EXTERIOR WALL AND CORRIDOR

Regression Output:

Constant		1.435367	
Std Err of Y Est		0.001737	
R Squared		0.999977	0.999988
No. of Observations		12	
Degrees of Freedom		10	
X Coefficient(s)	0.770299		
Std Err of Coef.	0.001166		

Regression equations to calculate the leakage characteristics of the exterior wall, ceiling, floor, left and right partitions plus the corridor wall.

REGRESSION EQUATION DESCRIBING EXTERIOR WALL & CORRIDOR LEAKAGE:

C = 4.201186

n = 0.770299

CEILING

Regression Output:

Constant		4.091846	
Std Err of Y Est		0.140377	
R Squared		0.830923	0.911550
No. of Observations		12	
Degrees of Freedom		10	
X Coefficient(s)	-0.66122		
Std Err of Coef.	0.094321		

REGRESSION EQUATION DESCRIBING CEILING LEAKAGE:

C = 59.85030

n = -0.66122

RIGHT PARTITION

Regression Output:

Constant		2.075727	
Std Err of Y Est		0.042053	
R Squared		0.592805	0.769938
No. of Observations		12	
Degrees of Freedom		10	
X Coefficient(s)	-0.10781		
Std Err of Coef.	0.028256		

REGRESSION EQUATION DESCRIBING RIGHT PARTITION LEAKAGE:

C = 7.970341

n = -0.10781

FLOOR

Regression Output:

Constant		2.422205	
Std Err of Y Est		0.063950	

R Squared		0.795018	0.891637
No. of Observations		12	
Degrees of Freedom		10	
X Coefficient(s)	-0.26760		
Std Err of Coef.	0.042969		

REGRESSION EQUATION DESCRIBING FLOOR LEAKAGE:

C = 11.27069

n = -0.26760

LEFT PARTITION

Regression Output:

Constant		1.069962	
Std Err of Y Est		0.013653	
R Squared		0.998295	0.999147
No. of Observations		12	
Degrees of Freedom		10	
X Coefficient(s)	0.702004		
Std Err of Coef.	0.009173		

REGRESSION EQUATION DESCRIBING LEFT PARTITION LEAKAGE:

C = 2.915269

n = 0.702004

RESULTS: AIR LEAKAGE RATES @ 50 Pa

CONDITION A: 6-SIDED LEAKAGE IGNORING DOOR

	LEAKAGE l/s	PERCENTAGE DISTRIBUTION
LEFT PARTITION	45.43	31.4 %
RIGHT PARTITION	5.23	3.6 %
FLOOR	3.96	2.7 %
CEILING	4.50	3.1 %
EXT. WALL & CORR.	85.52	59.1 %
TOTAL	144.64	100.00 %

EXTERIOR WALL AND CORRIDOR LEAKAGE PER SQUARE METRE OF EXTERIOR WALL: 7.03 l/s m2

CONDITION B: 6-SIDED LEAKAGE IGNORING WINDOW

	LEAKAGE l/s	PERCENTAGE DISTRIBUTION
DOOR	98.52	40.5 %
LEFT PARTITION	45.43	18.7 %
RIGHT PARTITION	5.23	2.1 %
FLOOR	3.96	1.6 %

CEILING	4.50	1.9 %
EXT. WALL & CORR.	85.52	35.2 %
TOTAL	243.16	100.00 %

EXTERIOR WALL AND CORRIDOR LEAKAGE PER SQUARE METRE OF EXTERIOR WALL: 7.03 l/s m2

WORKSHEET FOR CALCULATING THE REGRESSION EQN. OF A PARTITION USING THE DIFFERENCE BETWEEN TWO AIRTIGHTNESS TESTS.

BUILDING: A

TEST SUITE: 909

LEAKAGE CALCULATED: EXTERIOR WALL AND CORRIDOR

EXTERIOR WALL AREA: 12.17 m2

ANALYSIS:

Q6 – NO PRESSURE MASKING
C = 15.9189
n = 0.6218

Airtightness test results for the Test Suite without simultaneous depressurization of adjacent suites.

*Suite orientations as viewed from corridor looking into suite.

TOP SUITE PRESSURE MASKED
C = 15.6775
n = 0.5961

Airtightness test results for the Test Suite with simultaneous depressurization.

LEFT SUITE PRESSURE MASKED
C = 13.6276
n = 0.5953

RIGHT SUITE PRESSURE MASKED
C = 17.1164
n = 0.5881

BOTTOM SUITE PRESSURE MASKED
C = 16.8721
n = 0.5947

Pex	P b/d	Q6	Qc	Qr	Qf	Ql	Qrem.	ln(P ex)	ln(Qrem)
52	55	185.75	20.48	10.93	8.87	42.54	102.93	3.951243	4.634028
48	51	176.73	19.16	9.95	8.07	40.19	99.36	3.871201	4.598732
43	46	165.05	17.48	8.71	7.07	37.16	94.63	3.761200	4.549943
38	42	152.83	15.75	7.46	6.06	34.02	89.54	3.637586	4.494739
35	37	145.22	14.69	6.71	5.44	32.08	86.30	3.555348	4.457799
29	31	129.19	12.51	5.18	4.21	28.04	79.26	3.367295	4.372712
27	29	123.58	11.76	4.67	3.79	26.63	76.72	3.295836	4.340162
24	27	114.85	10.61	3.90	3.17	24.47	72.69	3.178053	4.286261
22	26	108.80	9.83	3.39	2.75	22.99	69.84	3.091042	4.246246
19	23	99.32	8.63	2.62	2.13	20.68	65.27	2.944438	4.178464
15	19	85.74	6.98	1.59	1.30	17.42	58.45	2.708050	4.068254

ln(P b/d)	ln(Qc)	ln(Qr)	ln(Qf)	ln(Ql)
4.007333	3.019488	2.391213	2.182549	3.7505287
3.931825	2.952961	2.297266	2.088504	3.6935851
3.828641	2.861009	2.164572	1.955704	3.6152188
3.737669	2.756915	2.009834	1.800889	3.5269992
3.610917	2.687194	1.903116	1.694151	3.4682153
3.433987	2.526265	1.645432	1.436548	3.3335083
3.367295	2.464533	1.541584	1.332790	3.2822129
3.295836	2.362041	1.361628	1.153080	3.1975321

3.258096	2.285704	1.220348	1.012081	3.1348665
3.135494	2.155810	0.961858	0.754347	3.0290693
2.944438	1.942686	0.464462	0.259531	2.8578931

REGRESSION EQUATIONS:

EXTERIOR WALL AND CORRIDOR

Regression Output:

Constant		2.840540		
Std Err of Y Est		0.001751		
R Squared		0.999915	r =	0.9999577
No. of Observations		11		
Degrees of Freedom		9		
X Coefficient(s)	0.454518			
Std Err of Coef.	0.001393			

REGRESSION EQUATION DESCRIBING EXTERIOR WALL & CORRIDOR LEAKAGE:

C = 17.12501

n = 0.454518

CEILING

Regression Output:

Constant		-0.93177		
Std Err of Y Est		0.036212		
R Squared		0.989983	r =	0.9949793
No. of Observations		11		
Degrees of Freedom		9		
X Coefficient(s)	0.992546			
Std Err of Coef.	0.033278			

REGRESSION EQUATION DESCRIBING CEILING LEAKAGE:

C = 0.393852

n = 0.992546

RIGHT PARTITION

Regression Output:

Constant		-4.36402		
Std Err of Y Est		0.113108		
R Squared		0.967855	r =	0.9837964
No. of Observations		11		
Degrees of Freedom		9		
X Coefficient(s)	1.711102			
Std Err of Coef.	0.103944			

REGRESSION EQUATION DESCRIBING RIGHT PARTITION LEAKAGE:

C = 0.012727

n = 1.711102

FLOOR

Regression Output:

Constant		-4.56399		
Std Err of Y Est		0.112252		
R Squared		0.968239	r =	0.9839916
No. of Observations		11		

Degrees of Freedom		9		
X Coefficient(s)	1.708728			
Std Err of Coef.	0.103158			

REGRESSION EQUATION DESCRIBING FLOOR LEAKAGE:

C = 0.010420

n = 1.708728

LEFT PARTITION

Regression Output:

Constant		0.460819		
Std Err of Y Est		0.027533		
R Squared		0.991613	r =	0.9957979
No. of Observations		11		
Degrees of Freedom		9		
X Coefficient(s)	0.825404			
Std Err of Coef.	0.025302			

REGRESSION EQUATION DESCRIBING LEFT PARTITION LEAKAGE:

C = 1.585372

n = 0.825404

RESULTS: AIR LEAKAGE RATES @ 50 Pa

CONDITION A: 6-SIDED LEAKAGE IGNORING DOOR

	LEAKAGE l/s	PERCENTAGE DISTRIBUTION
LEFT PARTITION	40.04	22.4 %
RIGHT PARTITION	10.28	5.7 %
FLOOR	8.34	4.7 %
CEILING	19.13	10.7 %
EXT. WALL & CORR.	101.35	56.6 %
TOTAL	179.13	100.00 %

EXTERIOR WALL AND CORRIDOR LEAKAGE PER SQUARE METRE OF EXTERIOR WALL: 8.33 l/s m2

CONDITION B: 6-SIDED LEAKAGE IGNORING WINDOW

	LEAKAGE l/s	PERCENTAGE DISTRIBUTION
DOOR	138.59	43.6 %
LEFT PARTITION	40.04	12.6 %
RIGHT PARTITION	10.28	3.2 %
FLOOR	8.34	2.6 %

CEILING	19.13	6.0 %
EXT. WALL & CORR.	101.35	31.9 %
TOTAL	317.72	100.00 %

EXTERIOR WALL AND CORRIDOR LEAKAGE PER SQUARE METRE OF EXTERIOR WALL: 8.33 l/s m2

WORKSHEET FOR CALCULATING THE REGRESSION EQN. OF A PARTITION USING THE DIFFERENCE BETWEEN TWO AIRTIGHTNESS TESTS.

BUILDING: B

TEST SUITE: 509

LEAKAGE CALCULATED: EXTERIOR WALL

EXTERIOR WALL AREA: 28.23 m2

ANALYSIS:

Q6 – NO PRESSURE MASKING
C = 22.0018
n = 0.5612

Airtightness test results for the Test Suite without simultaneous depressurization of adjacent suites.

*Suite orientations as viewed from corridor looking into suite.

TOP SUITE PRESSURE MASKED
C = 17.0784
n = 0.5714

Airtightness test results for the Test Suite with simultaneous depressurization.

LEFT & RIGHT SUITES & CORRIDOR PRESSURE MASKED
C = 17.9065
n = 0.5524

BOTTOM SUITE PRESSURE MASKED
C = 19.9903
n = 0.5458

Pex	P b/d	Q6	Qc	Qf	Ql,r,cor	Qrem	ln(P ex)	ln(Qrem)
54	56	206.38	39.53	30.04	44.21	92.60	3.988984	4.528329
51	53	199.87	38.38	28.94	42.73	89.82	3.931825	4.497758
47	49	190.91	36.79	27.44	40.71	85.98	3.850147	4.454074
45	47	186.31	35.97	26.67	39.67	84.00	3.806662	4.430817
41	43	176.83	34.27	25.10	37.54	79.92	3.713572	4.381030
40	39	174.40	33.83	24.69	36.99	78.87	3.688879	4.367824
36	35	164.38	32.03	23.05	34.75	74.55	3.583518	4.311476
33	33	156.55	30.62	21.77	33.00	71.16	3.496507	4.264941
31	31	151.15	29.64	20.89	31.80	68.82	3.433987	4.231505
28	29	142.76	28.11	19.54	29.93	65.17	3.332204	4.177072
27	28	139.87	27.59	19.08	29.29	63.92	3.295836	4.157623
26	27	136.94	27.05	18.61	28.64	62.64	3.258096	4.137440
23	24	127.84	25.38	17.16	26.63	58.67	3.135494	4.071874

ln(P b/d)	ln(Qc)	ln(Qf)	ln(Ql,r,c)
4.025351	3.677075	3.402566	3.7889358
3.970291	3.647455	3.365306	3.7550111
3.891820	3.605115	3.312007	3.7065261
3.850147	3.582568	3.283604	3.6807091
3.761200	3.534285	3.222738	3.6254332
3.663561	3.521474	3.206578	3.6107691

3.555348	3.466798	3.137557	3.5481896
3.496507	3.421626	3.080470	3.4964973
3.433987	3.389158	3.039401	3.4593483
3.367295	3.336282	2.972453	3.3988585
3.332204	3.317384	2.948504	3.3772416
3.295836	3.297769	2.923636	3.3548069
3.178053	3.234029	2.842741	3.2819120

REGRESSION EQUATIONS:

EXTERIOR WALL

Regression Output:

Constant		2.394977	
Std Err of Y Est		0.000002	
R Squared		0.999999	r = 0.9999999
No. of Observations		13	
Degrees of Freedom		11	
X Coefficient(s)	0.534809		
Std Err of Coef.	0.000002		

REGRESSION EQUATION DESCRIBING EXTERIOR WALL LEAKAGE:

C = 10.96795

n = 0.534809

CEILING

Regression Output:

Constant		1.618944	
Std Err of Y Est		0.014528	
R Squared		0.990599	r = 0.9952887
No. of Observations		13	
Degrees of Freedom		11	
X Coefficient(s)	0.512257		
Std Err of Coef.	0.015045		

REGRESSION EQUATION DESCRIBING CEILING LEAKAGE:

C = 5.047760

n = 0.512257

FLOOR

Regression Output:

Constant		0.802918	
Std Err of Y Est		0.018511	
R Squared		0.990438	r = 0.9952079
No. of Observations		13	
Degrees of Freedom		11	
X Coefficient(s)	0.647129		
Std Err of Coef.	0.019170		

REGRESSION EQUATION DESCRIBING FLOOR LEAKAGE:

C = 2.232046

n = 0.647129

LEFT, RIGHT, PARTITION CORRIDORS

Regression Output:

Constant		1.433481	
Std Err of Y Est		0.016603	
R Squared		0.990626	r = 0.9953020
No. of Observations		13	
Degrees of Freedom		11	
X Coefficient(s)	0.586245		
Std Err of Coef.	0.017194		

REGRESSION EQUATION DESCRIBING LEFT, RIGHT, CORR. LEAKAGE:

C = 4.193273

n = 0.586245

RESULTS: AIR LEAKAGE RATES @ 50 Pa

CONDITION A: 6-SIDED LEAKAGE IGNORING DOOR

	LEAKAGE l/s	PERCENTAGE DISTRIBUTION
L & R PART. & CORR.	41.55	21.2 %
FLOOR	28.06	14.3 %
CEILING	37.45	19.1 %
EXTERIOR WALL	88.87	45.4 %
TOTAL	195.93 l/s	100.00 %

EXTERIOR WALL LEAKAGE PER SQUARE METRE OF EXTERIOR WALL: 3.15 l/s m2

WORKSHEET FOR CALCULATING THE REGRESSION EQN. OF A PARTITION USING THE DIFFERENCE BETWEEN TWO AIRTIGHTNESS TESTS.

BUILDING: B

TEST SUITE: 609

LEAKAGE CALCULATED: EXTERIOR WALL

EXTERIOR WALL AREA: 28.23 m2

ANALYSIS:

Q6 – NO PRESSURE MASKING
C = 20.0891
n = 0.5753

Airtightness test results for the Test Suite without simultaneous depressurization of adjacent suites.

*Suite orientations as viewed from corridor looking into suite.

TOP SUITE PRESSURE MASKED
C = 16.6172
n = 0.6006

Airtightness test results for the Test Suite with simultaneous depressuriztion.

LEFT & RIGHT SUITES & CORRIDOR PRESSURE MASKED
C = 13.2000
n = 0.5919

BOTTOM SUITE PRESSURE MASKED
C = 16.7835
n = 0.5787

Pex	P b/d	Q6	Qc	Qf	Ql,r,cor	Qrem	ln(P ex)	ln(Qrem)
62	60.5	215.84	17.65	32.97	63.96	101.26	4.127134	4.617667
58	55.5	207.71	17.31	31.77	61.71	96.92	4.060443	4.573917
52	50.5	195.06	16.75	29.89	58.20	90.22	3.951243	4.502234
49	46.5	188.51	16.44	28.92	56.38	86.76	3.891820	4.463201
46	44.5	181.78	16.12	27.92	54.50	83.24	3.828641	4.421682
40	41.5	167.74	15.42	25.83	50.56	75.93	3.688879	4.329764
40	42.5	167.74	15.42	25.83	50.56	75.93	3.688879	4.329764
37	39.5	160.38	15.03	24.73	48.49	72.13	3.610917	4.278448
36	37.5	157.87	14.89	24.36	47.78	70.84	3.583518	4.260406
34	36.5	152.76	14.61	23.60	46.34	68.22	3.526360	4.222754
32	32.5	147.53	14.31	22.81	44.85	65.55	3.465735	4.182801
31	30.5	144.86	14.16	22.41	44.09	64.19	3.433987	4.161870
30	30.5	142.15	14.00	22.01	43.32	62.82	3.401197	4.140247
28	29.5	136.62	13.67	21.18	41.74	60.02	3.332204	4.094731
26	26.5	130.92	13.32	20.32	40.11	57.16	3.258096	4.045812
24	23.5	125.02	12.95	19.44	38.42	54.21	3.178053	3.992943
20	20.5	112.58	12.12	17.56	34.83	48.06	2.995732	3.872383

ln(P b/d)	ln(Qc)	ln(Qf)	ln(Ql,r,c)
4.102643	2.870843	3.495506	4.1582465
4.016383	2.851226	3.458395	4.1225029

3.921973	2.818301	3.397627	4.0639559
3.839452	2.799983	3.364556	4.0320852
3.795489	2.780210	3.329394	3.9981920
3.725693	2.735430	3.251603	3.9231844
3.749504	2.735430	3.251603	3.9231844
3.676300	2.709861	3.208207	3.8813259
3.624340	2.700779	3.192955	3.8666120
3.597312	2.681675	3.161136	3.8359116
3.481240	2.661187	3.127386	3.8033419
3.417726	2.650367	3.109711	3.7862824
3.417726	2.639128	3.091456	3.7686612
3.384390	2.615273	3.053044	3.7315774
3.277144	2.589344	3.011782	3.6917333
3.157000	2.560997	2.967213	3.6486859
3.020424	2.495168	2.865684	3.5505841

REGRESSION EQUATIONS:

EXTERIOR WALL

Regression Output:

Constant		1.900209	
Std Err of Y Est		0.000289	
R Squared		0.999998	r = 0.9999990
No. of Observations		17	
Degrees of Freedom		15	
X Coefficient(s)	0.658557		
Std Err of Coef.	0.000229		

REGRESSION EQUATION DESCRIBING EXTERIOR WALL LEAKAGE:

C = 6.687293

n = 0.658557

CEILING

Regression Output:

Constant		1.453365	
Std Err of Y Est		0.011658	
R Squared		0.988269	r = 0.9941173
No. of Observations		17	
Degrees of Freedom		15	
X Coefficient(s)	0.346182		
Std Err of Coef.	0.009738		

REGRESSION EQUATION DESCRIBING CEILING LEAKAGE:

C = 4.277488

n = 0.346182

FLOOR

Regression Output:

Constant		1.102738	
Std Err of Y Est		0.021957	
R Squared		0.985296	r = 0.9926212
No. of Observations		17	

Degrees of Freedom	15	
X Coefficient(s)	0.581502	
Std Err of Coef.	0.018341	

REGRESSION EQUATION DESCRIBING FLOOR LEAKAGE:

C = 3.012403

n = 0.581502

LEFT, RIGHT, PARTITION CORRIDORS

Regression Output:

Constant	1.849968		
Std Err of Y Est	0.021136		
R Squared	0.985362	r =	0.9926542
No. of Observations	17		
Degrees of Freedom	15		
X Coefficient(s)	0.561012		
Std Err of Coef.	0.017654		

REGRESSION EQUATION DESCRIBING LEFT, RIGHT, CORR. LEAKAGE:

C = 6.359616

n = 0.561012

RESULTS: AIR LEAKAGE @50 Pa

CONDITION A: 6-SIDED LEAKAGE IGNORING DOOR

	LEAKAGE l/s	PERCENTAGE DISTRIBUTION
L & R PART. & CORR.	57.09	29.9 %
FLOOR	29.30	15.3 %
CEILING	16.57	8.7 %
EXTERIOR WALL	87.93	46.1 %
TOTAL	190.89 l/s	100.00 %

EXTERIOR WALL LEAKAGE PER SQUARE METRE OF EXTERIOR WALL: 3.11 l/s m2

WORKSHEET FOR CALCULATING THE REGRESSION EQN. OF A PARTITION USING THE DIFFERENCE BETWEEN TWO AIRTIGHTNESS TESTS.

BUILDING: B

TEST SUITE: 1009

LEAKAGE CALCULATED: EXTERIOR WALL

EXTERIOR WALL AREA: 28.23 m2

ANALYSIS:

WINDOW SEALED
C = 12.9992
n = 0.621

Q6 – NO PRESSURE MASKING
C = 14.3858
n = 0.6132

Airtightness test results for the Test Suite without simultaneous depressurization of adjacent suites.

*Suite orientations as viewed from corridor looking into suite.

TOP SUITE PRESSURE MASKED
C = 13.5768
n = 0.5896

Airtightness test results for the Test Suite with simultaneous depressurization.

LEFT & RIGHT SUITES & CORRIDOR PRESSURE MASKED
C = 13.6809
n = 0.5363

BOTTOM SUITE PRESSURE MASKED
C = 9.3647
n = 0.6669

Pex	P b/d	Q6	Qc	Qf	Ql,r,cor	Qrem	ln(P ex)	ln(Qrem)
60	61	177.13	25.36	33.47	54.18	64.12	4.094344	4.160828
55	55	167.93	23.75	32.37	50.58	61.24	4.007333	4.114740
53	53	164.16	23.09	31.90	49.12	60.05	3.970291	4.095148
52	52	162.25	22.76	31.66	48.38	59.45	3.951243	4.085080
46	48	150.50	20.73	30.17	43.88	55.72	3.828641	4.020374
45	47	148.49	20.39	29.90	43.11	55.08	3.806662	4.008792
44	46	146.45	20.04	29.63	42.34	54.43	3.784189	3.996956
40	40	138.14	18.64	28.51	39.22	51.77	3.688879	3.946821
38	38	133.86	17.92	27.92	37.62	50.39	3.637586	3.919881
37	38	131.69	17.56	27.62	36.82	49.69	3.610917	3.905886
35	36	127.28	16.83	26.99	35.19	48.27	3.555348	3.876748
32	34	120.47	15.70	26.01	32.71	46.05	3.465735	3.829829
28	30	111.00	14.17	24.58	29.30	42.95	3.332204	3.760068
27	27	108.55	13.77	24.21	28.43	42.14	3.295836	3.741099
25	24	103.55	12.97	23.42	26.67	40.49	3.218875	3.701001

ln(P b/d)	ln(Qc)	ln(Qf)	ln(Ql,r,c)
4.110873	3.233110	3.510631	3.9922985
4.007333	3.167376	3.477087	3.9235903
3.970291	3.139338	3.462662	3.8942368
3.951243	3.124906	3.455211	3.8791174

3.871201	3.031806	3.406734	3.7813907
3.850147	3.015076	3.397951	3.7637940
3.828641	2.997958	3.388942	3.7457771
3.688879	2.925211	3.350422	3.6690795
3.637586	2.885961	3.329488	3.6276067
3.637586	2.865527	3.318550	3.6059886
3.583518	2.822884	3.295639	3.5608168
3.526360	2.753939	3.258365	3.4876064
3.401197	2.650776	3.202106	3.3776380
3.295836	2.622588	3.186640	3.3474979
3.178053	2.562804	3.153716	3.2834361

REGRESSION EQUATIONS:

EXTERIOR WALL

Regression Output:

Constant		2.009908	
Std Err of Y Est		0.000382	
R Squared		0.999993	r = 0.9999966
No. of Observations		15	
Degrees of Freedom		13	
X Coefficient(s)	0.525169		
Std Err of Coef.	0.000376		

REGRESSION EQUATION DESCRIBING EXTERIOR WALL LEAKAGE:

C = 7.462633

n = 0.525169

CEILING

Regression Output:

Constant		0.113756	
Std Err of Y Est		0.022677	
R Squared		0.988979	r = 0.9944743
No. of Observations		15	
Degrees of Freedom		13	
X Coefficient(s)	0.757901		
Std Err of Coef.	0.022189		

REGRESSION EQUATION DESCRIBING CEILING LEAKAGE:

C = 1.120478

n = 0.757901

FLOOR

Regression Output:

Constant		1.849727	
Std Err of Y Est		0.011633	
R Squared		0.989794	r = 0.9948844
No. of Observations		15	
Degrees of Freedom		13	
X Coefficient(s)	0.404190		
Std Err of Coef.	0.011382		

REGRESSION EQUATION DESCRIBING FLOOR LEAKAGE:

C = 6.358083

n = 0.404190

LEFT, RIGHT, PARTITION CORRIDORS

Regression Output:

Constant		0.694758		
Std Err of Y Est		0.023620		
R Squared		0.989307	r =	0.9946394
No. of Observations		15		
Degrees of Freedom		13		
X Coefficient(s)	0.801575			
Std Err of Coef.	0.023112			

REGRESSION EQUATION DESCRIBING LEFT, RIGHT, CORR. LEAKAGE:

C = 2.003224

n = 0.801575

WINDOW

Regression Output:

Constant		0.387627		
Std Err of Y Est		0.000402		
R Squared		0.999992	r =	0.9999960
No. of Observations		15		
Degrees of Freedom		13		
X Coefficient(s)	0.509941			
Std Err of Coef.	0.000395			

REGRESSION EQUATION DESCRIBING WINDOW LEAKAGE:

C = 1.473480

n = 0.509941

RESULTS: AIR LEAKAGE @ 50Pa

CONDITION A: 6-SIDED LEAKAGE IGNORING DOOR

	LEAKAGE l/s	PERCENTAGE DISTRIBUTION
L & R PART. & CORR.	46.09	29.4 %
FLOOR	30.91	19.7 %
CEILING	21.73	13.8 %
EXTERIOR WALL	58.23	37.1 %
TOTAL	156.95 l/s	100.00 %

EXTERIOR WALL LEAKAGE PER SQUARE METRE OF EXTERIOR WALL: 2.06 l/s m2

WINDOW LEAKAGE (EXCLUDING ROUGH-OPENING)

	LEAKAGE l/s
WINDOW	10.83 l/s

BUILDING: A

BATHROOM EXHAUST FLOW RATES (l/s)					
SUITE	VENTILATION SYSTEM				
	READING	ON	READING	OFF	ON–OFF
304	30	8.33	15	4.17	4.17
305	20	5.56	15	4.17	1.39
403	20	5.56	20	5.56	0.00
405	20	5.56	10	2.78	2.78
409	30	8.33	30	8.33	0.00
605	16	4.44	15	4.17	0.28
702	23	6.39	20	5.56	0.83
909	23	6.39	30	8.33	–1.94
1109	38	10.56	40	11.11	–0.56

IMPACT OF VENTILATION SYSTEM (l/s):			
	VENTILATION SYSTEM		
FLOOR	ON	OFF	IMPACT
14TH	237.2	61.0	176.2
12TH	110.2	0.0	110.2
11TH	213.8	0.0	213.8
10TH	232.0	–18.0	250.0
9TH	344.2	0.0	344.2
8TH	287.6	0.0	287.6
7TH	358.5	–5.6	364.1
6TH	290.5	0.0	290.5
5TH	360.5	–27.8	388.3
4TH	324.5	0.0	324.5
3RD	269.4	–61.0	330.4
2ND	183.6	–69.4	253.0
AVERAGE	267.7	–10.1	277.7

BUILDING: B

BATHROOM EXHAUST FLOW RATES (l/s)					
SUITE	VENTILATION SYSTEM				
	READING	ON	READING	OFF	ON-OFF
207	20	5.56	10	2.78	2.78
509	30	13.53	15	8.07	5.47
609	15	9.37	5	6.59	2.78
908	15	4.17	5	1.39	2.78
1009	30	9.63	10	10.58	-0.94
1208	22	6.11	5	1.39	4.72
1406	25	8.24	5	3.99	4.26

*READING IS ACIN FLOW HOOD VALUE FOR CEILING GRILLE ONLY, SUITES 509,609,1009 AND 1406 ALSO HAVE WALL GRILLES, WHOSE CONTRIBUTION HAS BEEN ADDED TO THE "ON" AND "OFF" VALUES.

IMPACT OF VENTILATION SYSTEM (l/s):			
	VENTILATION SYSTEM		
FLOOR	ON	OFF	IMPACT
14TH	207.4	53.0	154.4
12TH	464.2	102.5	361.7
11TH	454.4	81.5	372.9
10TH	535.3	89.9	445.4
9TH	490.8	96.2	394.6
8TH	388.6	36.6	352.0
7TH	339.2	5.8	333.4
6TH	278.8	2.1	276.7
5TH	392.1	-57.5	449.6
4TH	282.3	-65.1	347.3
3RD	397.3	-67.4	464.7
2ND	453.1	-87.1	540.2
AVERAGE	390.3	15.9	374.4

BUILDING: A

ENVELOPE PRESSURE DIFFERENTIAL MEASUREMENTS

SUITE	WALL DELTA P (Pa)					HEIGHT
	VENTILATION ON		VENTILATION OFF		ON–OFF	AB. GRD.
	(″ H20)	(Pa)	(″ H20)	(Pa)	(Pa)	(m)
304	–0.053	–13.20	–0.094	–23.42	10.2	6.27
305	–0.053	–13.20	–0.101	–25.16	12.0	6.27
403	–0.048	–11.96	–0.088	–21.92	10.0	8.89
405	–0.047	–11.71	–0.088	–21.92	10.2	8.89
409	–0.037	–9.22	–0.081	–20.18	11.0	8.89
605	–0.038	–9.47	–0.065	–16.19	6.7	14.13
702	–0.021	–5.23	–0.05	–12.46	7.2	16.74
909	0.004	1.00	–0.018	–4.48	5.5	21.98
1109	0.015	3.74	0.007	1.74	2.0	27.21
				AVERAGE	8.30	Pa

MEAN FLOOR VALUES	DELTA P ON (Pa)	DELTA P OFF (Pa)	HEIGHT AB. GRD. (m)
3	–13.20	–24.29	6.27
4	–10.96	–21.34	8.89
6	–9.47	–16.19	14.13
7	–5.23	–12.46	16.74
9	1.00	–4.48	21.98
11	3.74	1.74	27.21

NOMENCLATURE: –ve INDICATES INFILTRATION

BUILDING: B

ENVELOPE PRESSURE DIFFERENTIAL MEASUREMENTS						
SUITE	WALL DELTA P (Pa)					HEIGHT
	VENTILATION ON		VENTILATION OFF		ON-OFF	AB. GRD.
	(" H20)	(Pa)	(" H20)	(Pa)	(Pa)	(m)
207	-0.032	-7.8	-0.036	-9.0	1.1	3.4
509	-0.016	-4.0	-0.032	-8.0	4.0	11.2
908	-0.007	-1.7	-0.031	-7.7	6.0	21.7
1009	0.000	0.0	-0.023	-5.6	5.6	24.3
1208	0.009	2.2	0.000	0.0	2.2	29.5
1406	0.011	2.6	0.005	1.2	1.4	34.8
				AVERAGE	3.38	Pa

NOMENCLATURE: -ve INDICATES INFILTRATION

APPENDIX D
AIR QUALITY
DATA COLLECTED

TABLE 1
SPACE TEMPERATURES - BUILDING A
February 20-27, 1991

Suite Number	No. of Occupants	No. of Readings	Dry Bulb Temperature, °C		
			Mean	Maximum	Minimum
1404	1	83	27.6	29.5	25.0
1204	*	83	27.4	28.5	24.5
1104	1	82	28.0	29.0	24.5
1004	1	82	29.2	30.5	29.5
606	2	81	27.7	29.0	24.5
503	*	81	25.8	27.0	25.5
209	2	82	25.6	27.0	25.0
Lounge	-	82	25.0	28.0	22.5

* not reported

The range of temperatures recorded (+24.5°C to +30.5°C) would be considered excessive by the majority of people. Temperatures of +20°C to +25°C would be considered normal. The temperature/relative humidity recording apparatus is shown in Photograph #1.

PHOTOGRAPH #1: Temperature/Humidity Recorder

TABLE 2

SPACE TEMPERATURES - BUILDING B

March 8-13, 1991

Suite Number	No. of Readings	Dry Bulb Temperature, °C		
		Mean	Maximum	Minimum
1205	60	27.4	28.0	26.9
1107	60	27.5	27.9	26.9
1106	60	27.3	28.7	26.4
803	56	28.5	28.8	27.8
702	60	25.9	27.0	25.2
610	59	22.3	23.0	21.7
402	60	28.0	28.7	27.4
Lounge	60	24.3	24.9	23.8

The range of temperatures recorded (+24.5°C to +30.5°C) at Building A, and the range of temperatures recorded (+21.7°C to +28.8°C) at Building B, would be considered excessive by the majority of people. Temperatures of +20°C o +25°C would be considered normal.

TABLE 3

RELATIVE HUMIDITIES - BUILDING A

February 20-27, 1991

Suite Number	No. of Readings	Dry Bulb Temperature, °C		
		Mean	Maximum	Minimum
1404	81	17.0	26.0	13.0
1204	82	18.2	26.0	15.0
1104	81	11.9	18.0	9.0
1004	72	21.3	25.0	19.5
606	81	27.0	32.0	22.5
503	81	14.5	20.0	12.0
209	81	27.3	33.0	23.0
Lounge	85	19.7	29.0	15.5

TABLE 4

RELATIVE HUMIDITIES - BUILDING B

March 8-18, 1991

Suite Number	No. of Readings	Dry Bulb Temperature, °C		
		Mean	Maximum	Minimum
1404	60	32.8	35.5	30.5
1107	60	28.2	30.7	26.3
1106	60	20.7	22.7	18.9
803	57	24.6	29.1	22.2
702	57	17.9	19.1	17.0
610	60	28.0	28.7	27.3
402	61	20.5	22.4	18.2
Lounge	60	16.1	17.8	14.4

PHOTOGRAPH #2: Carbon Dioxide and Carbon Monoxide Monitoring Equipment

TABLE 5

CARBON DIOXIDE LEVELS - BUILDING A

February 20-27, 1991

Suite Number	No. of Occupants	No. of Readings	CO_2 Levels, mg/m^3 (ppm)					
			Mean		Maximum		Minimum	
1404	1	13	700	(390)	1,260	(700)	450	(250)
1204	*	13	490	(270)	720	(400)	450	(250)
1104	1	9	880	(490)	1,800	(1,000)	450	(250)
1004	1	10	970	(540)	1,260	(700)	720	(400)
606	2	10	1,190	(660)	1,800	(1,000)	540	(300)
503	*	10	400	(220)	540	(300)	450	(250)
209	2	11	850	(470)	1,080	(600)	630	(350)

* not reported

TABLE 6

CARBON DIOXIDE LEVELS - BUILDING B

March 8-18, 1991

Suite Number	No. of Readings	CO_2 Levels, mg/m^3 (ppm)					
		Mean		Maximum		Minimum	
1205	24	1,730	(960)	1,800	(1,000)	1,620	(900)
1107	24	1,240	(690)	1,350	(750)	1,130	(630)
1106	24	1,620	(640)	1,670	(930)	1,040	(580)
803	24	1,150	(820)	1,220	(680)	1,440	(800)
702	24	1,480	(590)	1,580	(880)	900	(500)
402	24	970	(540)	1,080	(600)	950	(530)

TABLE 7

CARBON MONOXIDE LEVELS - BUILDING A

February 20-27, 1991

Suite Number	No. of Readings	CO Levels, mg/m^3 (ppm)					
		Mean		Maximum		Minimum	
1404	13	1.6	(0.9)	2.2	(1.2)	<0.9	(<0.5)*
1205	13	1.5	(0.8)	1.8	(1.0)	1.3	(0.7)
1104	9	<0.9	(<0.5)	0.9	(0.5)	<0.9	(<0.5)
1004	10	1.1	(0.6)	1.1	(0.6)	0.9	(0.5)
606	10	2.0	(1.1)	2.2	(1.2)	1.5	(0.8)
503	10	<0.9	(<0.5)	<0.9	(<0.5)	<0.9	(<0.5)
209	11	1.5	(0.8)	1.8	(1.0)	0.9	(0.5)

* detection limit

TABLE 8

CARBON MONOXIDE LEVELS - BUILDING B

March 8-18, 1991

Suite Number	No. of Readings	CO Levels, mg/m^3 (ppm)					
		Mean		Maximum		Minimum	
1205	24	1.6	(0.9)	1.8	(1.0)	0	(0)
1107	24	4.5	(2.5)	5.4	(3.0)	3.6	(2.0)
1106	24	13.1	(7.3)	14.4	(8.0)	9.0	(5.0)
803	24	8.8	(4.9)	9.0	(5.0)	7.2	(4.0)
702	24	2.3	(1.3)	3.6	(2.0)	1.8	(1.0)
610	24	3.2	(1.8)	3.6	(2.0)	1.8	(1.0)
402	24	0.9	(0.5)	1.8	(1.0)	0	(0)

TABLE 9

BUILDINGS A & B

BACTERIOLOGICAL TESTING

BUILDING A			BUILDING B		
Suite Number	Bacteria Count Colonies	Mold Count Number	Suite Number	Bacteria Count Colonies	Mold Count Number
1404	20	0	1205	19	<1
1204	2	0	1107	<1	<1
1104	9	0	1106	45	<1
1004	19	0	803	6	<1
606	105	0	702	21	<1
503	8	0	610	<1	<1
209	14	0	402	<1	<1
Lounge	<1	0	Lounge	5	<1

TABLE 10
BUILDINGS A & B
FORMALDEHYDE TESTING

Apartment	Suite Number	Formaldehyde Concentration mg/m^3	ppm*
Building A	1404	< 0.01	< 0.006
Building B	1205	< 0.01	< 0.006

* detection limit

PHOTOGRAPH #3: Particulate Sampling Cassette

TABLE 11

AIRBORNE PARTICULATE LEVELS - BUILDING A

February 20-27, 1991

Suite Number	Air Volume Sampled, Litre	Particulate Concentration, Ug/m^3
1404	2,850	456
1204	2,970	33
1104	2,776	36
1004	2,800	35
606	2,880	<34
503	2,990	<33
209	3,206	<31

TABLE 12

AIRBORNE PARTICULATE LEVELS - BUILDING B

March 12-18, 1991

Suite Number	Air Volume Sampled, Litre	Particulate Concentration, Ug/m^3
1205	120	4,170
1107	120	12,500
1106	120	32,500
803	120	20,883
702	120	15,000
610	120	< 833
402	120	16,667

FIGURE 1: BUILDING A

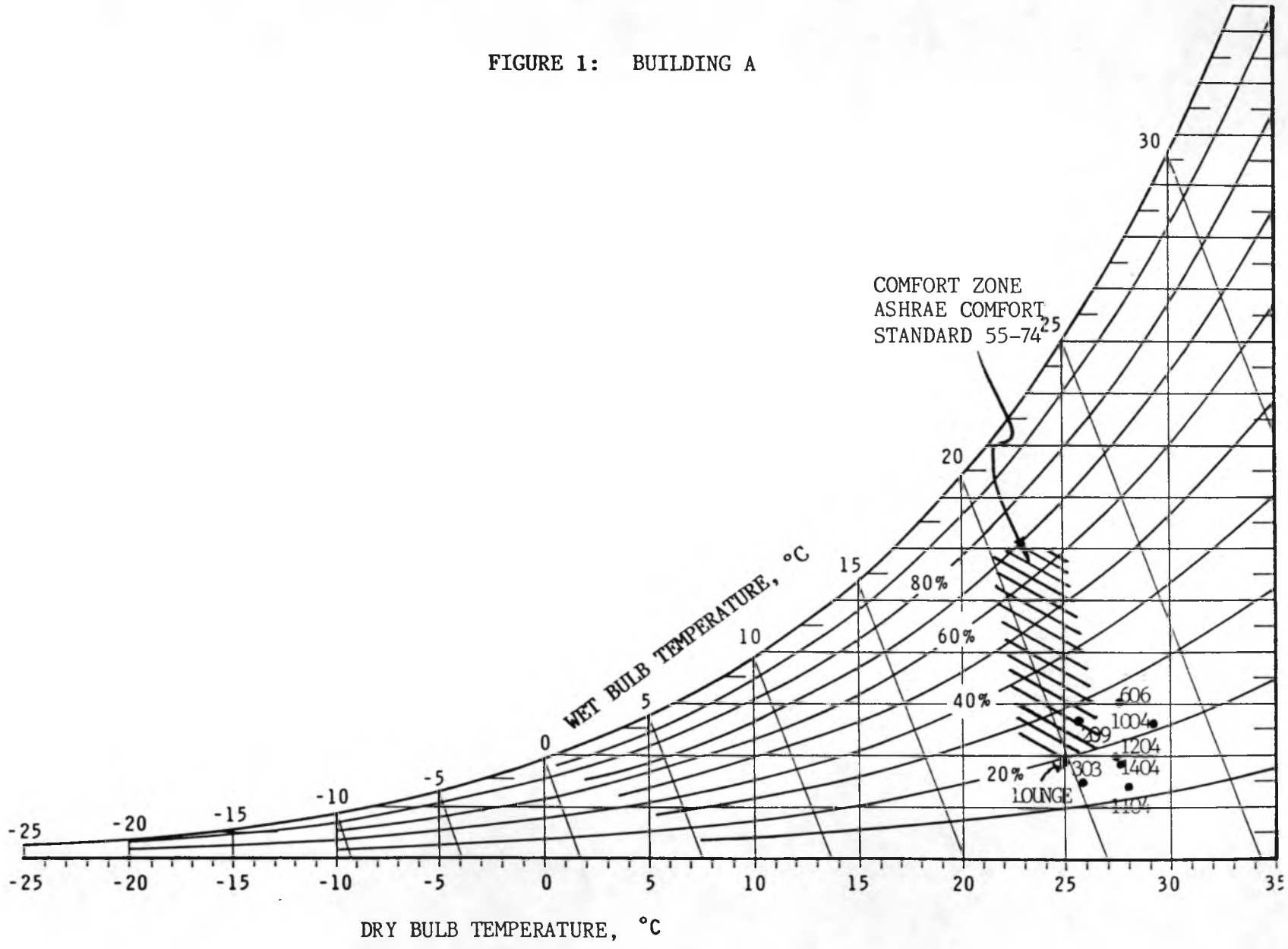
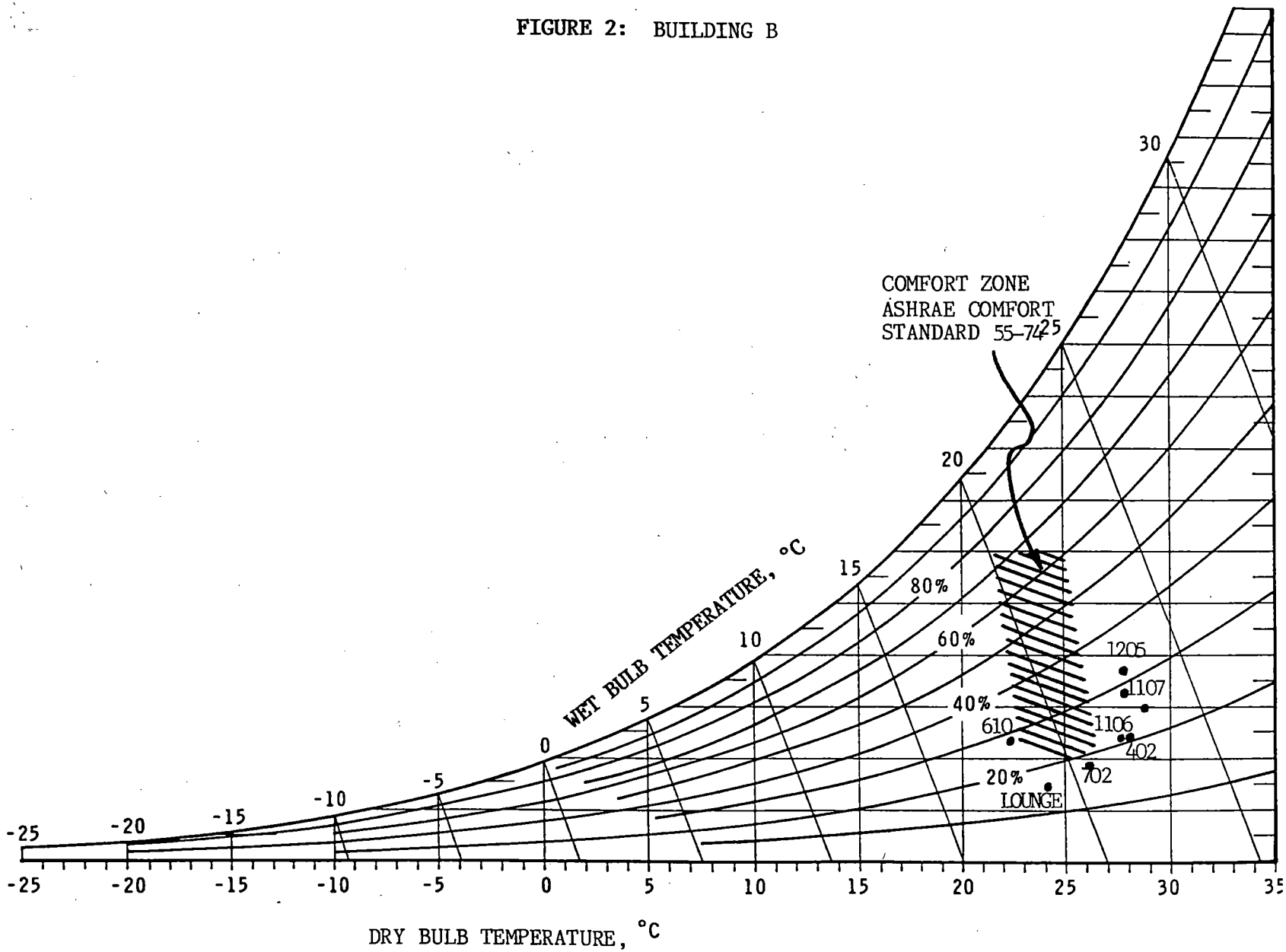


FIGURE 2: BUILDING B



APPENDIX E
COMMENTARY ON AIRTIGHTNESS AND AIR MOVEMENT TEST PROTOCOL

APPENDIX E

COMMENTARY ON AIRTIGHTNESS AND AIR MOVEMENT

The following comments are based on observations made during the project and are offered both with respect to the two buildings tested, as well as their general application to other structures. They also reflect possible implications for commercialization of the testing procedure.

A. Test Procedures

1. Airtightness Testing

The basic test procedure of using a single blower to provide sequential pressure-masking of adjacent suites worked satisfactorily. The advantages of this technique over the simultaneous pressure-masking procedure using four blowers (Shaw, 1990) included: significantly reduced equipment and manpower requirements; fewer accessibility problems (since only one or two suites had to be accessed simultaneously with the test suite); and easier establishment of stabilized conditions since one, instead of four, pressure differentials had to be maintained at zero.

The main disadvantage was that the technique may not as effectively neutralize the effects of network leakage (ie. that which occurs through a complex path involving more than one adjacent suite), since all adjacent suites are not depressurized at the same time.

CAN/CGSB-149.120-M86 (Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method) requires the leakage rate be measured at eight indoor-to-outdoor pressure differentials ranging from 50 Pa to 15 Pa. Considering the significant time required to prepare for each test, it was decided to collect a larger number of data points - typically 12 to 17. This proved to be a correct decision since the analysis often required several data points to be rejected.

Weather proved to be the most persistent problem. Approximately half the scheduled testing days/periods had to be cancelled due to high winds. CAN/CGSB-149.10-M86 recommends airtightness testing not be conducted if the wind speed is greater than 20 km/hr, and this proved to be the practical limit (using airport wind velocity reports), provided the test suite was located on the leeward side of the building. If the suite was on the windward side, or in the shadow of a vortex being shed off the corner of the building, lower speeds were often necessary.

2. Exterior Wall Pressure Differential Measurements

The exterior wall pressure differential measurements were straightforward although they required low wind conditions to produce reliable results: the maximum wind velocity which could be tolerated appears to be about 10 km/hr.

When conducting exterior wall pressure differential measurements, it is important to develop a clear objective for the tests. Natural forces (stack effect and wind) will produce a wide range of indoor-to-outdoor pressure differentials in any tall building, and simply measuring their magnitude and direction at an instance in time, or over a period of time, is of limited value. For the project buildings, it was decided that two useful pieces of information, which the testing could produce, would be the degree of pressurization created by the mechanical ventilation system and the height of the neutral pressure plane. The former provided insight on the extent to which the ventilation system might aggravate an air exfiltration/moisture transport problem, while the latter offered information on the vertical distribution of envelope leakage since the presence of large holes in the air barrier tends to draw the neutral plane towards the location of those holes.

B. Equipment and Instrumentation

Several versions of the corridor mask were constructed and evaluated, and the final model proved to be satisfactory, requiring approximately 1.0 to 1.5 manhours/mask to assemble in the hallway. In the case of Building A, two masks were required on either side of the adjacent suites, whereas in Building B, a single mask was used because a corridor door was available which could be shut to close off that side of the hallway.

The only significant equipment problem was the reliability of the blower used to provide pressure masking of adjacent suites. The unit (Minneapolis Blower Door) suffered repeated thermal overloads which automatically shut down the motor due to the low airflows, resulting in insufficient cooling. This added considerably to the time required to perform some of the tests.

The instrumentation used in the project worked satisfactorily, although we recommend that only high quality electronic micromanometers, of the type used, be employed for pressure measurements. Inclined manometers and magnehelic gauges were not found to provide sufficient resolution or accuracy for assessing indoor-to-outdoor or flow nozzle pressure differentials, although they were acceptable for stabilizing pressures between suites.

Electronic interference between the two-way radios used for communication between operators and the micromanometers occurred, but was generally a minor problem.

C. Analysis

Airtightness test results were calculated using the procedure in CAN/CGSB-149.10-M86 to produce the flow coefficient (C) and the flow exponent (n) for a regression equation of the form $Q = C\Delta p^n$. These results were entered into a Lotus spreadsheet in which the component leakage was calculated as the difference between the masked and unmasked regression curves.

Most aspects of the analysis were straightforward, except in those instances in which small leakage rates were encountered, for example, across some floor/ceiling separations. Since the partition leakage was calculated as the difference between the regression curves from two separate tests, the results were very sensitive to experimental error. In some cases, it was not possible to achieve flow exponents between the desired values of 0.5 and 1.0.

One aspect of the analysis which warrants further development is the method of correcting the nozzle air flow rates for temperature. CAN/CGSB-149.10-M86 applies a correction based on the indoor and outdoor temperatures which assumes that all of the air flowing through the nozzle (or other flow measuring device) has entered the building at the outdoor ambient temperature and then been heated or cooled until its temperature equals that of the individual suite within a multi-family structure. A more sophisticated approach is probably required since a significant component of the air leaking into the suite will be from adjacent suites, and thus not at the temperature of the outdoor air. Shaw (1990) suggests that testing only be conducted when the indoor-to-outdoor temperature differential is less than 10°C, however, this would seriously restrict the opportunities to perform such tests, particularly in colder climates. At this point, we simply wish to flag it for consideration in the development of standard(s) for testing multi-family buildings.

Based on our experiences, we do not believe that corridor partition leakage can be reliably and accurately estimated on the basis of the left and right partition leakage. In the cases of suites #409 and #909 in Building A, the exterior wall leakage included the corridor wall leakage. Shaw (1990) has suggested that the corridor wall leakage can be

estimated by averaging the left and right partition wall leakage on a unit area basis, if similar construction details are used. This method was considered but rejected for suites #409 and #909 because the left and right partition wall leakages differed significantly (by factors of 9 and 4, respectively). Therefore, if the exterior wall leakage is desired, some form of corridor mask arrangement will be necessary.

D. Accessibility

Accessibility to the suites was a problem, although not as major as anticipated. Both buildings were publicly owned and the Housing Authority was quite cooperative. Further, the assistance received from the management/maintenance personnel was excellent. However, in some instances gaining access to individual suites proved difficult because the tenants were at work, or ill or simply chose not to cooperate. Since both buildings were seniors' residences, most of tenants were home during the day. If this had not been the case, accessibility would have been a major problem since access to the buildings was restricted to normal working hours during the week.

Another factor which minimized accessibility problems was that both buildings contained large numbers of unoccupied suites. All of the test suites were selected from this group since testing tied up the suite for at least two days and in some cases, for several weeks. They also provided convenient equipment storage areas and served as bases for operations.

E. Cost Estimate

For illustrative purposes, the cost to conduct a series of airtightness tests on a single suite of a typical multi-family building was estimated based on our experiences on the two buildings. The testing included in this estimate would evaluate the air leakage characteristics of the a) total envelope (ie. the six-sided leakage); b) exterior wall; c) ceiling; d) floor; and e) the combined left and right partitions, plus the corridor partition. The estimate assumed that the service would be delivered on a commercial basis by an engineering firm familiar with the experimental procedures and possessing the necessary equipment. Testing would be performed by one engineer and one technician with analysis by the engineer. It was assumed that the building layout would permit the use of a corridor mask so that the exterior wall leakage could be determined independent of the corridor partition leakage.

Preparation (building visit, drawings review, test planning, fabrication of corridor masks)	
Engineer (1.0 man/day @ $520)	$ 520
Technician (1.0 man/day @ $320)	320
Testing	
Engineer (1.5 man/day @ $520)	780
Technician (1.5 man/day @ $320)	480
Analysis and Reporting	
Engineer (1.5 man/day @ $520)	780
Equipment Allowance	
(2% x $10,000 x 1.5 days)	300
Supplies and Miscellaneous	100
Subtotal	3,280
Contingency 10%	330
	3,610
GST	255
TOTAL	$3,865
Say	$4,000

This estimate also assumed that good access was available to the building and all required suites, a factor which may be a problem with many occupied multi-family residential buildings. The weather was also assumed to be relatively cooperative without extended periods of high winds. While high winds simply dictate that the day's testing be postponed, continued delays could seriously affect the project schedule and tie up the test equipment. Testing which is being conducted away from the testing firm's home city should therefore be carefully discussed with the client since it may be prudent to insist on night-time access to minimize wind problems.

A firm wishing to develop this expertise should be prepared to make a considerable investment in time and expenses to acquire the necessary experience and capabilities, and to develop or purchase the testing equipment and analysis software.

APPENDIX F
INDOOR AIR QUALITY SURVEY RESULTS

SUMMARY OF

INDOOR AIR QUALITY SURVEY

BUILDING A

WINNIPEG, MANITOBA

	18 - 30		31 - 60		Over 60			
Age			7	8%	82	92%		
	Male		Female					
Sex	19	21%	70	79%				
	1		2		3		More than 3	
Number of Occupants	75	91%	7	9%				
Smokers	Yes		No					
Cigarettes	13	16%	68	84%				
Cigars	-	-	81	100%				
Pipe	-	-	81	100%				
	1 - 5 hours		5 - 10 hours		Over 10			
Time in apt.	5	6%	22	27%	56	67%		
	Yes		No					
Operable Windows	77	98%	1	2%	4did not respond			
Control	Yes		No					
Temperature	63	77%	19	23%				
Ventilation	38	46%	44	54%				
Lighting	80	97%	2	3%				
Humidity	21	26%	61	74%				
	Never		Rarely		Sometimes		Always	
Too little air movement	5	8%	6	9%	31	48%	23	35%

	Never		Rarely		Sometimes		Always	
Too much air movement	34	74%	6	13%	6	13%	-	
Just right air movement	15	34%	2	4%	20	45%	8	17%
Air too dry	3	4%	4	6%	20	29%	41	61%
Air too moist	31	67%	13	29%	2	4%	-	
Humidity just right	12	26%	12	26%	12	26%	10	22%
Air too smokey	31	57%	7	13%	11	20%	5	10%
Air too stuffy	14	26%	5	9%	23	43%	12	22%
Unpleasant odours in the air	27	47%	8	14%	20	34%	3	5%
Temperature too hot	14	25%	11	20%	21	38%	9	17%
Temperature too cold	29	60%	10	21%	8	17%	1	2%
Temperature just right	7	13%	5	10%	24	45%	17	32%
Lighting too bright	34	76%	8	18%	2	4%	1	2%
Lighting too dim	23	44%	5	10%	10	19%	14	27%
Lighting just right	11	23%	1	2%	7	14%	30	61%
Too noisy	40	75%	8	15%	5	10%	-	-
Too quiet	35	71%	1	2%	10	21%	3	6%
Noise level just right	10	15%	-	-	13	19%	45	66%

	Yes		No					
Portable heater	9	11%	72	89%		2 ceiling fans		
Table top fan	43	53%	38	47%				
Portable air cleaner	8	10%	72	90%				
Portable humidifier	29	36%	52	64%				
Negative ion generator	1	1%	81	99%				
Radio/piped music	36	44%	46	56%				

	Fluorescent		Incandescent		Table Lamps		Window	
Lighting type	2	1%	38	21%	77	41%	69	37%

	Gas Stove		Electric Stove		Microwave		Other	
Cooking appliance	-	-	78	70%	24	21%	10	9%

	Forced air		Radiators		Fireplace		Port. Heater		Stove	
Heating	18	25%	48	66%	-	-	4	5%	3	4%

	Yes		No	
Air Cond.	66	85%	12	15%

	Central		Window-Type	
Type	-	-	66	100%

	Glue	Vinegar	Alcohol	Ammonia	Propane	Gas	Perfume	Other
Smells like	-	-	-	1 - 7 %	1 - 7 %	1-6%	3 - 20 %	9 - 60 %

	Smokey		Dusty		Musty		Stale		Other	
Smells	6	16%	4	11%	2	5%	18	47%	8	21%

	Never		Rarely		Sometimes		Always	
Headache	15	26%	17	29%	23	39%	3	6%
Fever	22	55%	14	35%	4	10%	-	
Dizziness	16	32%	15	30%	18	36%	1	2%
Fatigue	12	24%	5	10%	28	57%	4	9%
Sleepiness	14	27%	12	24%	23	45%	2	4%
Weakness	19	43%	10	22%	15	33%	1	2%
Nausea	22	49%	12	27%	11	24%	-	-
Respiratory problems	20	38%	7	13%	14	27%	11	22%
Muscular aches	16	32%	10	20%	16	32%	8	16%
Chest pain/tight	20	36%	10	18%	19	34%	7	12%
Backache	14	27%	5	9%	17	33%	16	31%
Neckache	17	39%	3	6%	17	39%	7	16%
Eye irritation	21	37%	5	9%	24	43%	6	11%

	Never		Rarely		Sometimes		Always	
Trouble focusing eyes	24	59%	4	10%	8	19%	5	12%
Sore/irritated throat	17	31%	8	14%	23	42%	7	13%
Nose irritation	14	23%	8	13%	30	49%	9	15%
Cold/flu symptoms	15	28%	16	30%	21	39%	2	3%
Depression	23	47%	11	22%	13	27%	2	4%
Difficulty concentrating	23	47%	8	16%	15	31%	3	6%
Tension/nervous	18	37%	10	20%	16	33%	5	10%
Skin dryness, rash, itching	12	18%	5	7%	32	48%	18	27%
Cold extremities	21	42%	6	12%	17	34%	6	12%
Hearing disturbances	23	46%	8	16%	17	34%	2	4%
Insomnia	22	40%	9	16%	21	38%	3	6%
Nose bleeds	30	59%	9	18%	12	23%	-	-
	Yes		No					
Migraine	6	8%	68	92%				
Asthma	5	7%	67	93%				
Eczema	8	11%	64	89%				
Hayfever/allergies	12	17%	59	83%				
Relief when away from apt.	19	45%	23	55%				

SUMMARY OF

INDOOR AIR QUALITY SURVEY

BUILDING B

WINNIPEG, MANITOBA

	18 - 30		31 - 60		Over 60			
Age			18	42%	25	58%		
	Male		Female					
Sex	19	44%	24	56%				
	1		2		3		More than 3	
Number of Occupants	35	90%	4	10%				
Smokers	Yes		No					
Cigarettes	17	42.5%	23	57.5%				
Cigars	-	-	39	100%				
Pipe	-	-	39	100%				
	1 - 5 hours		5 - 10 hours		Over 10			
Time in apt.	1	3%	5	13%	32	84%		
	Yes		No					
Operable Windows	38	100%	-				Windows frozen in winter	
Control	Yes		No					
Temperature	35	90%	4	10%				
Ventilation	17	43.5%	22	56.5%				
Lighting	37	95%	2	5%				
Humidity	4	10%	35	90%				
	Never		Rarely		Sometimes		Always	
Too little air movement	4	11%	7	20%	8	23%	16	46%

	Never		Rarely		Sometimes		Always	
Too much air movement	16	53%	9	30%	4	13%	1	4%
Just right air movement	12	39%	6	19%	3	10%	10	32%
Air too dry	4	12%	4	12%	7	20%	19	56%
Air too moist	20	65%	5	16%	5	16%	1	3%
Humidity just right	17	61%	5	18%	2	7%	4	14%
Air too smokey	17	53%	5	16%	8	25%	2	6%
Air too stuffy	6	17%	3	9%	12	34%	14	40%
Unpleasant odours in the air	8	24%	8	24%	13	40%	4	12%
Temperature too hot	5	15%	3	9%	20	61%	5	15%
Temperature too cold	10	32%	8	26%	12	39%	1	3%
Temperature just right	7	23%	6	20%	13	43%	4	14%
Lighting too bright	22	71%	4	13%	2	6%	3	10%
Lighting too dim	7	26%	4	15%	4	15%	12	44%
Lighting just right	13	45%	5	17%	4	14%	7	24%
Too noisy	15	50%	8	27%	5	17%	2	6%
Too quiet	12	44%	8	30%	2	7%	5	19%
Noise level just right	3	10%	3	10%	11	35%	14	45%

	Yes		No	
Portable heater	1	3%	36	97%
Table top fan	26	68%	12	32%
Portable air cleaner	2	6%	34	94%
Portable humidifier	10	27%	27	73%
Negative ion generator	-	-	37	100%
Radio/piped music	12	32%	25	68%

	Fluorescent		Incandescent		Table Lamps		Window	
Lighting type	-	-	27	30%	35	40%	27	30%

	Gas Stove		Electric Stove		Microwave		Other	
Cooking appliance	-	-	37	79%	7	15%	3	6%

	Forced air		Radiators		Fireplace		Port. Heater		Stove	
Heating	7	19%	27	75%	-	-	1	3%	1	3%

	Yes		No	
Air Cond.	-	-	36	100%

	Central		Window-Type	
Type				

	Glue	Vinegar	Alcohol	Ammonia	Propane	Gas	Perfume	Other
Smells like	-	-	-	2 - 50%	-	-	2 - 50%	-

	Smokey		Dusty		Musty		Stale		Other	
Smells	3	9%	6	17%	8	23%	18	51%	-	-

	Never		Rarely		Sometimes		Always	
Headache	6	23%	7	27%	12	46%	1	4%
Fever	13	59%	4	18%	5	23%	-	-
Dizziness	12	50%	4	17%	7	29%	1	4%
Fatigue	5	21%	2	8%	14	58%	3	13%
Sleepiness	4	16%	3	12%	15	60%	3	12%
Weakness	10	43%	6	26%	5	22%	2	9%
Nausea	13	59%	7	32%	2	9%	-	-
Respiratory problems	12	52%	3	13%	7	30%	1	5%
Muscular aches	8	31%	2	8%	11	42%	5	19%
Chest pain/tight	12	55%	3	14%	6	27%	1	4%
Backache	5	19%	2	7%	14	52%	6	22%
Neckache	7	32%	3	13.5%	9	41%	3	13.5%
Eye irritation	9	36%	6	24%	6	24%	4	16%

	Never		Rarely		Sometimes		Always	
Trouble focusing eyes	13	59%	4	18%	4	18%	1	5%
Sore/irritated throat	12	48%	3	12%	9	36%	1	4%
Nose irritation	9	27%	9	27%	12	35%	4	11%
Cold/flu symptoms	9	31%	8	28%	12	41%	-	-
Depression	13	47%	6	21%	9	32%	-	-
Difficulty concentrating	15	50%	7	23%	7	23%	1	4%
Tension/nervous	13	43%	7	23%	9	30%	1	4%
Skin dryness, rash, itching	7	22%	4	12%	15%	47%	6	19%
Cold extremities	15	53%	3	7%	8	29%	3	11%
Hearing disturbances	16	57%	5	18%	4	14%	3	11%
Insomnia	14	47%	6	20%	9	30%	1	3%
Nose bleeds	25	86%	2	7%	1	3.5%	1	3.5%

	Yes		No	
Migraine	4	11%	31	89%
Asthma	5	14%	30	86%
Eczema	1	3%	34	97%
Hayfever/allergies	6	17%	29	82%
Relief when away from apt.	12	48%	13	52%

APPENDIX G
INDOOR AIR QUALITY
SURVEY FORM

THE NATIONAL TESTING LABORATORIES LIMITED
Established in 1923

199 Henlow Bay
Winnipeg,Manitoba R3Y 1G4
Phone (204) 488-6999
Fax (204) 488-6947

INDOOR AIR QUALITY SURVEY

This survey is being used to determine the quality of the indoor environment of your apartment. Your assistance in completing the following questions as accurately as possible is very much appreciated. All information will be treated as confidential and anonymous and will be used for analyses only. Questions are answered using a √ mark.

NOTE: This survey is part of a larger national survey to obtain data on indoor air quality in apartment buildings. Your apartment building was randomly selected and there is no reason to believe that the indoor air quality is better of worse than the average of other apartment buildings.

APARTMENT ADDRESS: _____ DATE: _____

WILL THIS FORM BE COMPLETED BY: _____ 1 PERSON OR _____ GROUP OF OCCUPANTS

GENERAL INFORMATION

1. Age, Years
   - _____ 18 - 30
   - _____ 31 - 60
   - _____ Over 60

2. Sex
   - _____ Male
   - _____ Female

3. Number of Occupants
   - _____ 1
   - _____ 2
   - _____ 3
   - _____ More than 3

4. Are there smokers in the apartment?

Cigarettes _____ yes _____ no

Cigars _____ yes _____ no

Pipe _____ yes _____ no

5. On the average, how many hours a day are you in the apartment?

_____ 1 to 5

_____ 5 to 10

_____ over 10

APARTMENT INFORMATION

6. COMMENTS: _____

_____

_____

7. Are there operable windows in your apartment?

_____ yes

_____ no

COMMENTS: _____

_____

_____

8. Are you able to control the following (choose all that apply in your apartment)?

_____ temperature _____ lighting

_____ ventilation _____ humidity

9. In your apartment, how often do each of the following conditions occur?

	NEVER	RARELY	SOMETIMES	ALWAYS
(a) Too little air movement	_____	_____	_____	_____
(b) Too much air movement	_____	_____	_____	_____
(c) Just the right air movement	_____	_____	_____	_____
(d) Air too dry	_____	_____	_____	_____
(e) Air too moist	_____	_____	_____	_____
(f) Humidity just right	_____	_____	_____	_____
(g) Air too smokey	_____	_____	_____	_____
(h) Air too stuffy	_____	_____	_____	_____
(i) Unpleasant odours in the air	_____	_____	_____	_____
(j) Temperature too hot	_____	_____	_____	_____
(k) Temperature too cold	_____	_____	_____	_____
(l) Temperature just right	_____	_____	_____	_____
(m) Lighting too bright	_____	_____	_____	_____
(n) Lighting too dim	_____	_____	_____	_____
(o) Lighting just right	_____	_____	_____	_____
(p) Too noisy	_____	_____	_____	_____
(q) Too quiet	_____	_____	_____	_____
(r) Noise level just right	_____	_____	_____	_____

10. Do you have and use any of the following in your apartment:

_____ Portable heater
_____ Table top fan
_____ Portable air cleaner
_____ Portable humidifier
_____ Negative ion generator
_____ Radio/Piped music

11. How is yourapartment lit? (choose all that apply)

_____ Fluorescent ceiling light
_____ Incandescent ceiling light
_____ Table lamps
_____ Natural window light

12. Which of the following cooking appliances are used in your apartment? (choose all that apply)

_____ Gas stove
_____ Electric stove
_____ Microwave oven
_____ Other

13. What types of heating systems are used in your apartment? (choose all that apply)

_____ Forced air
_____ Radiators
_____ Fireplace
_____ Portable heater
_____ Stove

14. Is your apartment air conditioned?

_____ Yes
_____ No

15. If yes, what type of air conditioning system?

_____ Central
_____ Window-Type

16. If there is a smell in your apartment, how would you describe the smell?

(a) The smell resembles:

glue	_____	propane	_____
vinegar	_____	gasoline	_____
alcohol	_____	perfume	_____
ammonia	_____	other (specify)	_____

(b) It smells:

smoky	_____	stale	_____
dusty	_____	other (specify)	_____
musty	_____		

SYMPTOMS

17. Have any of the following symptoms been experienced while in the apartment?

	NEVER	RARELY	SOMETIMES	ALWAYS
Headache	_____	_____	_____	_____
Fever	_____	_____	_____	_____
Dizziness	_____	_____	_____	_____
Fatigue	_____	_____	_____	_____
Sleepiness	_____	_____	_____	_____
Weakness	_____	_____	_____	_____
Nausea	_____	_____	_____	_____
Respiratory problems	_____	_____	_____	_____
Muscular aches	_____	_____	_____	_____
Chest pain or tightness	_____	_____	_____	_____
Backache	_____	_____	_____	_____
Neckache	_____	_____	_____	_____
Eye irritation	_____	_____	_____	_____
Trouble focusing eyes	_____	_____	_____	_____
Sore or irritated throat	_____	_____	_____	_____

		NEVER	RARELY	SOMETIMES	ALWAYS
17.	Nose irritation (itching or running)	_____	_____	_____	_____
	Cold/Flu symptoms	_____	_____	_____	_____
	Depression	_____	_____	_____	_____
	Difficulty concentrating	_____	_____	_____	_____
	Tension or nervousness	_____	_____	_____	_____
	Skin dryness, rash or itching	_____	_____	_____	_____
	Cold extremities (feet, hands, etc.)	_____	_____	_____	_____
	Hearing disturbances	_____	_____	_____	_____
	Insomnia	_____	_____	_____	_____
	Nose bleeds	_____	_____	_____	_____

18. Does anyone in the apartment suffer from any of the following?

Migraine	_____ yes	_____ no
Asthma	_____ yes	_____ no
Eczema	_____ yes	_____ no
Hayfever or other allergies	_____ yes	_____ no

19. Is there any relief from these symptoms when away from the apartment?

_____ yes

_____ no

Thank you for your assistance in this survey. It is very important that <u>all survey forms are returned</u>. We would ask that the forms be returned to the building manager upon completion.