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# 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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APPENDICES

## 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.

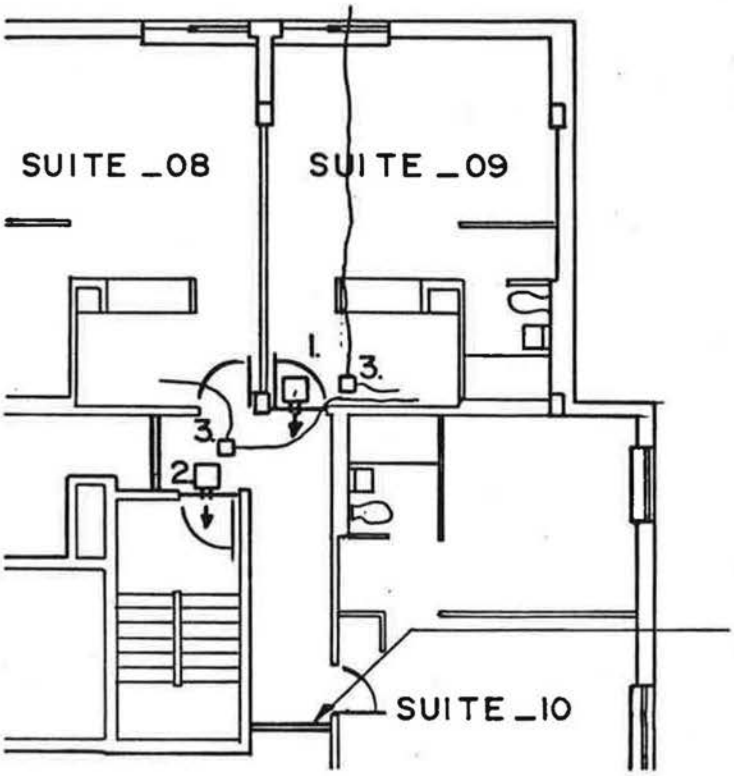
## 2.3 HVAC - BUILDING B

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.

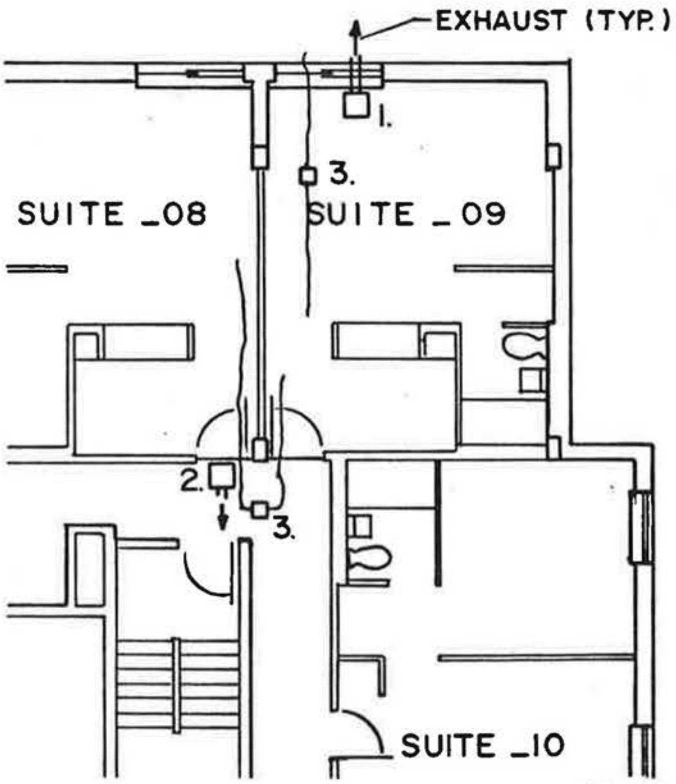
Ventilation air is not supplied to any of the suites directly. During the summer, fresh air is supplied to each floor through a single supply air grille located in the hallway. In the winter, the air is strictly recirculated air. In the summer, dampers on the make-up units are manually opened for ventilation 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




## TEST CONDITION B




LEGEND:

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

| | |
|---|---|
| CLIENT | CANADA MORTGAGE AND HOUSING CORPORATION |
| DWG. DESCRIPTION | AIR LEAKAGE TEST EQUIP. LAYOUT WITH CORRIDOR BARRIER MASKS |

**WARDROP ENGINEERING INC.**
WINNIPEG TORONTO THUNDER BAY EDMONTON

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

WS023-(08/87)

## 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.

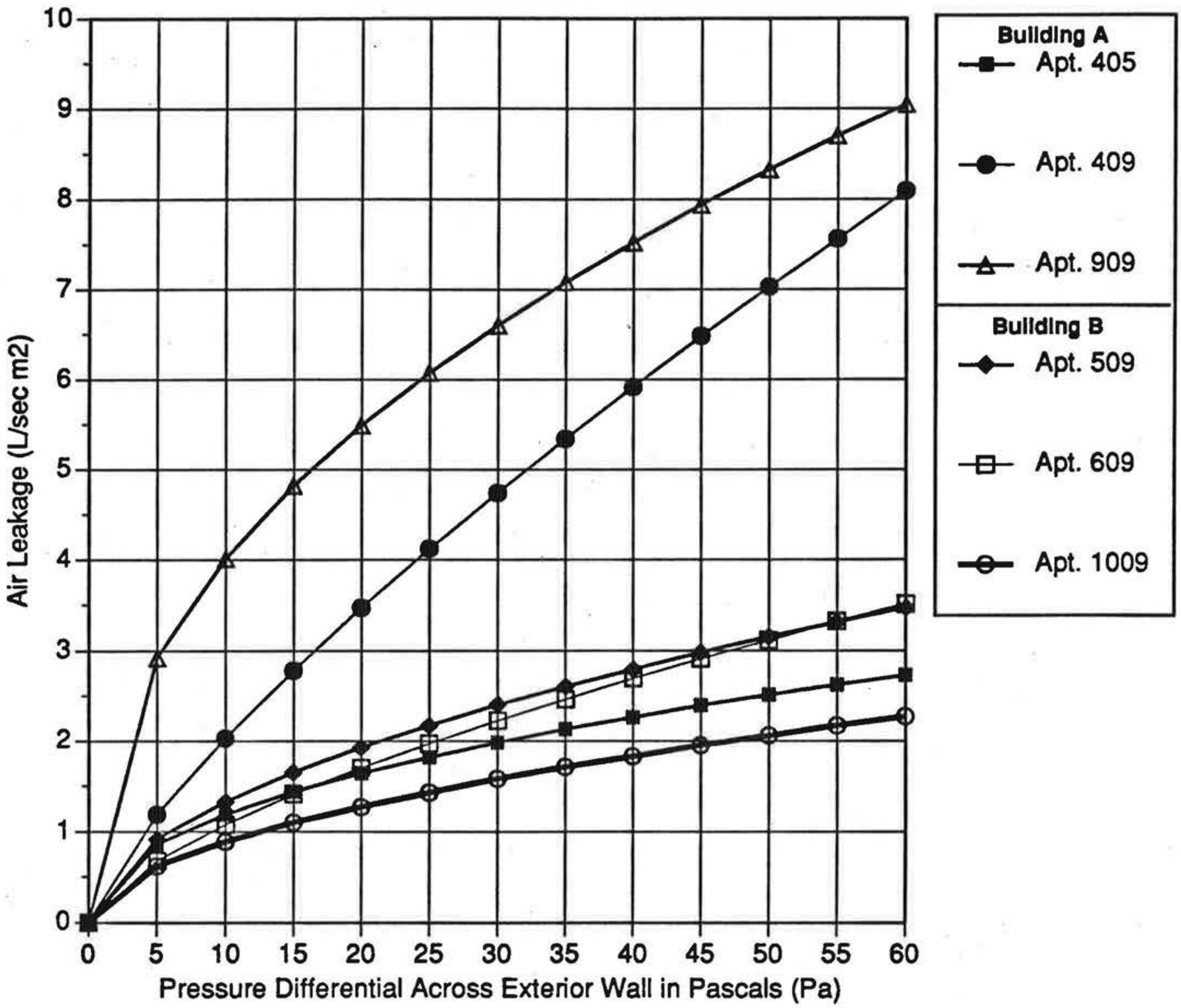
### 4.3.2 Test Parameters and Equipment

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

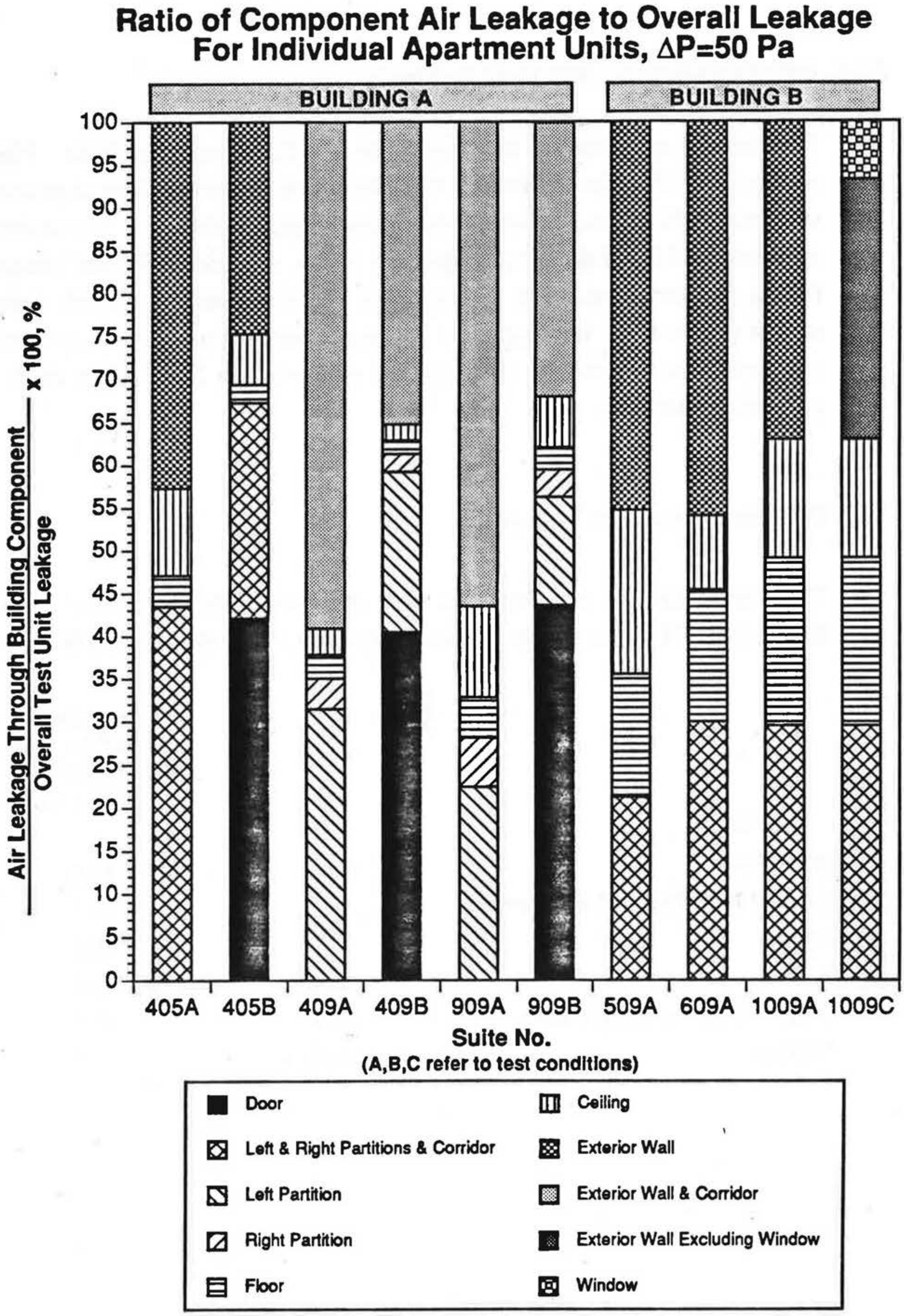
Again, as it was not possible to install the corridor barrier masks, the final airtightness results describe the combined air leakage across the exterior wall and the corridor partitions. The leakage rate was found to be 8.33 L/sec.m$^2$ at 50 Pa. This combined leakage represented 56.6% and 31.9% of 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
BUILDING A
BUILDING B
Air Leakage Through Building Component
Overall Test Unit Leakage
x 100, %
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
405A
405B
409A
409B
909A
909B
509A
609A
1009A
1009C
Suite No.
(A,B,C refer to test conditions)
Door
Left & Right Partitions & Corridor
Left Partition
Right Partition
Floor
Ceiling
Exterior Wall
Exterior Wall & Corridor
Exterior Wall Excluding Window
Window


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 |

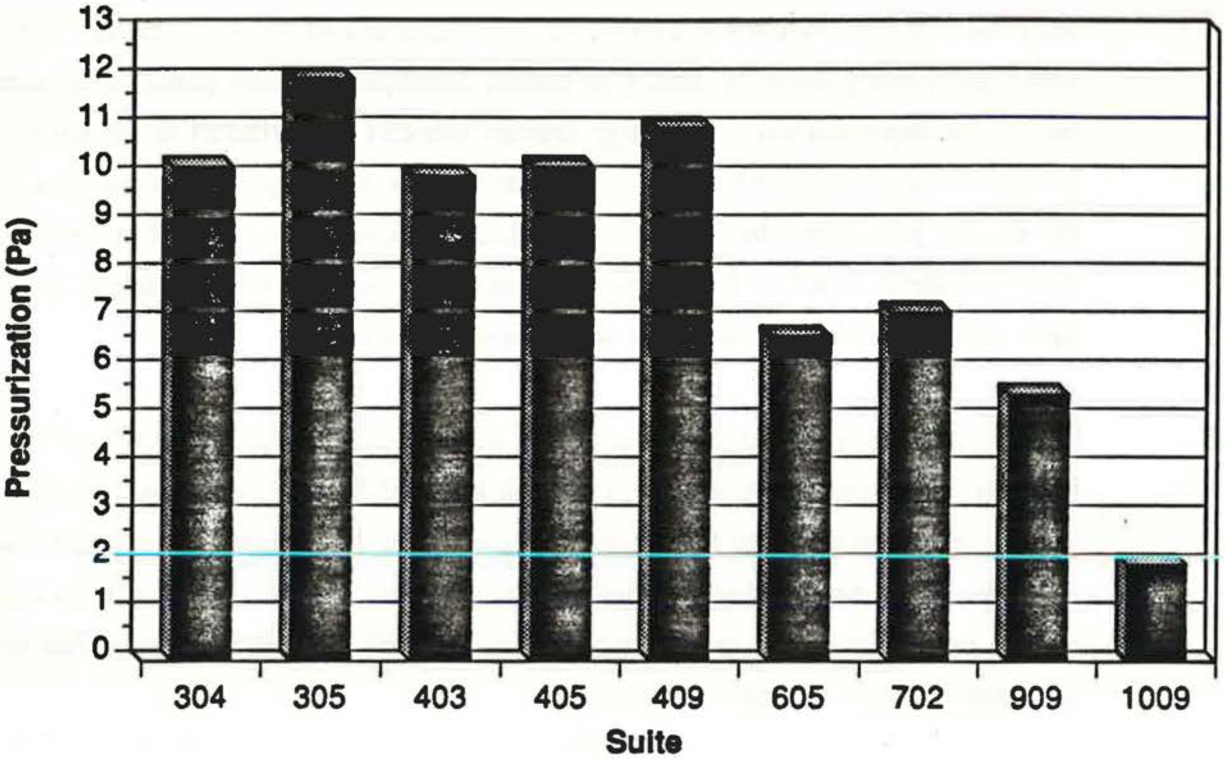
The largest single air leakage component was the suite entry door at 41.5% of the total six-sided leakage. While not unexpected, the magnitude of the door leakage should be noted, particularly since the testing procedure described by Shaw (circa 1990) does not include its determination. This large leakage 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.

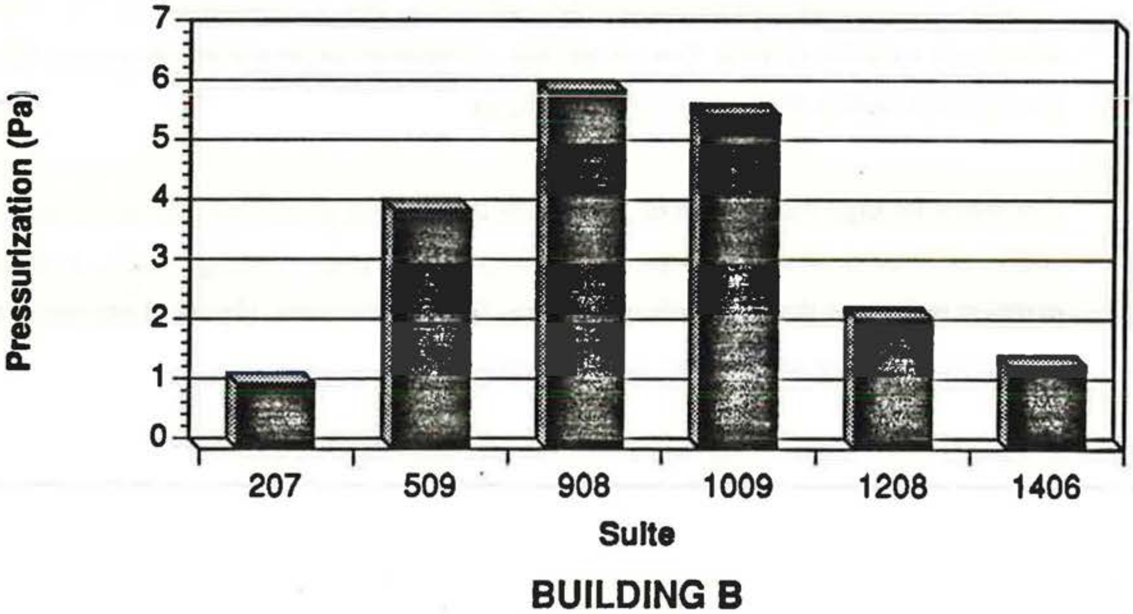
The leakage rates for the individual partition and corridor walls vary widely, but when averaged, each account for approximately 6.3% of the total leakage. This was essentially the same leakage rate found for the floors at 6.2%, and the ceilings at 6.7%. It is this direct type of suite to suite flow 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.

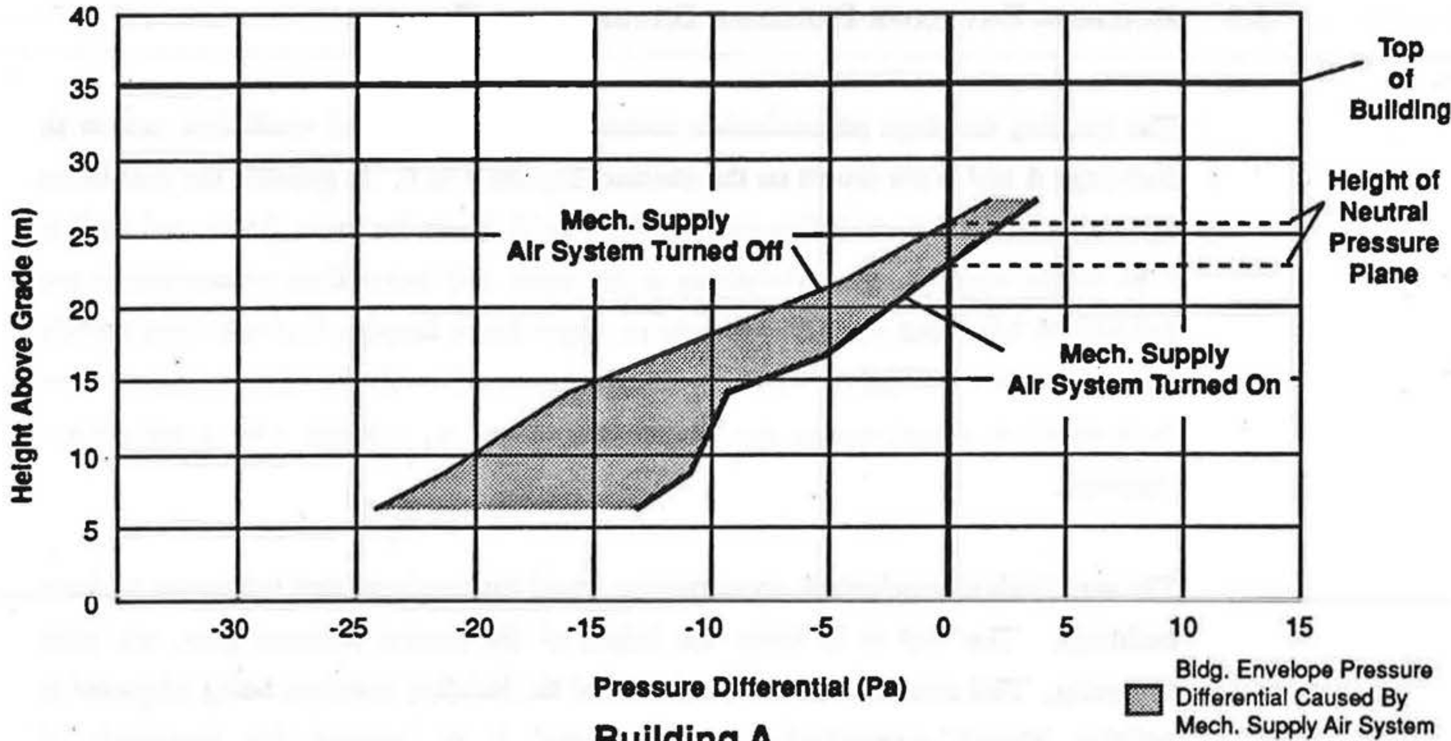
The magnitude of mechanical pressurization found has two important influences on these buildings. The first is to lower the height of the neutral pressure plan, see page following. This results in an increased area of the building envelope being subjected to positive internal pressurization. The second 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

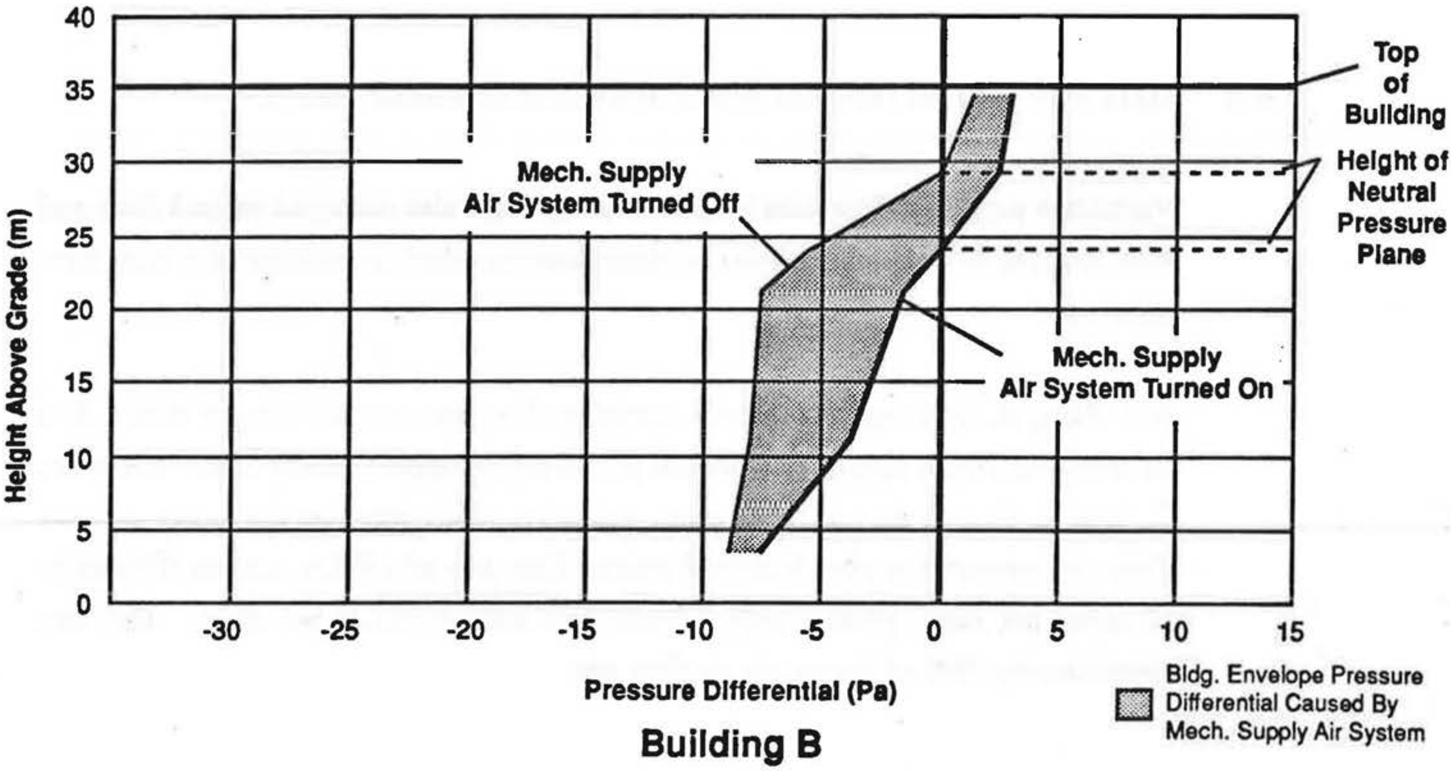
Ventilation supply air flow rates in both buildings were also measured on each floor and were found to be reasonably similar on those floors on which the exhaust flow rates were measured.

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.

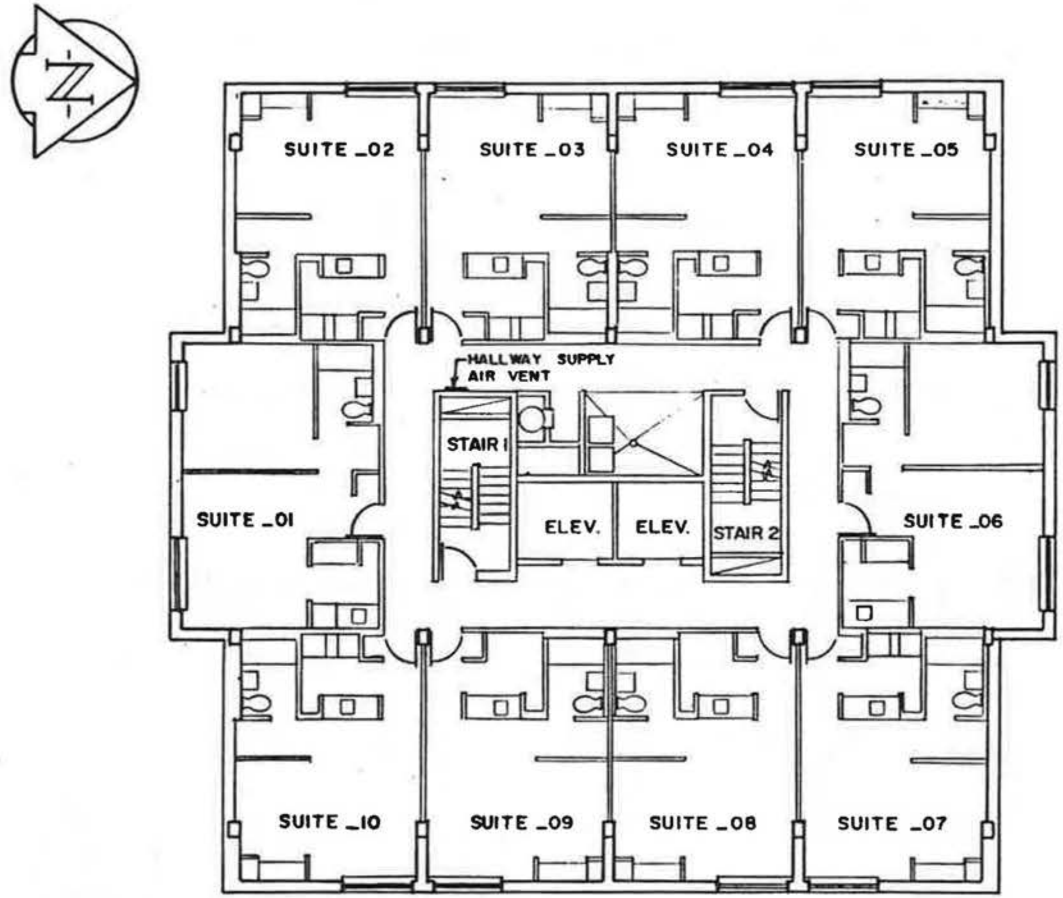
The results of airborne particulates for both buildings are included in Tables 11 and 12, Appendix D.

## 7.0 CORRECTIVE ACTIONS

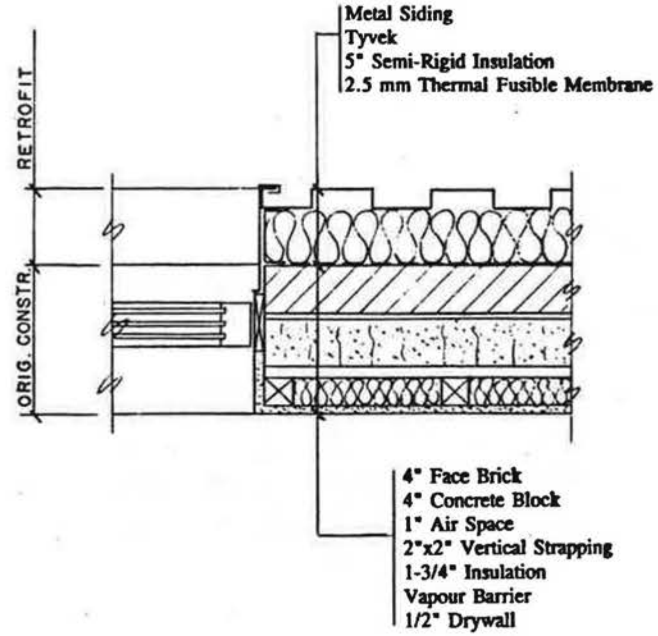
In conjunction with the building owners, corrective actions are being determined to reduce the carbon dioxide and airborne particulate levels in both buildings.

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 | | |

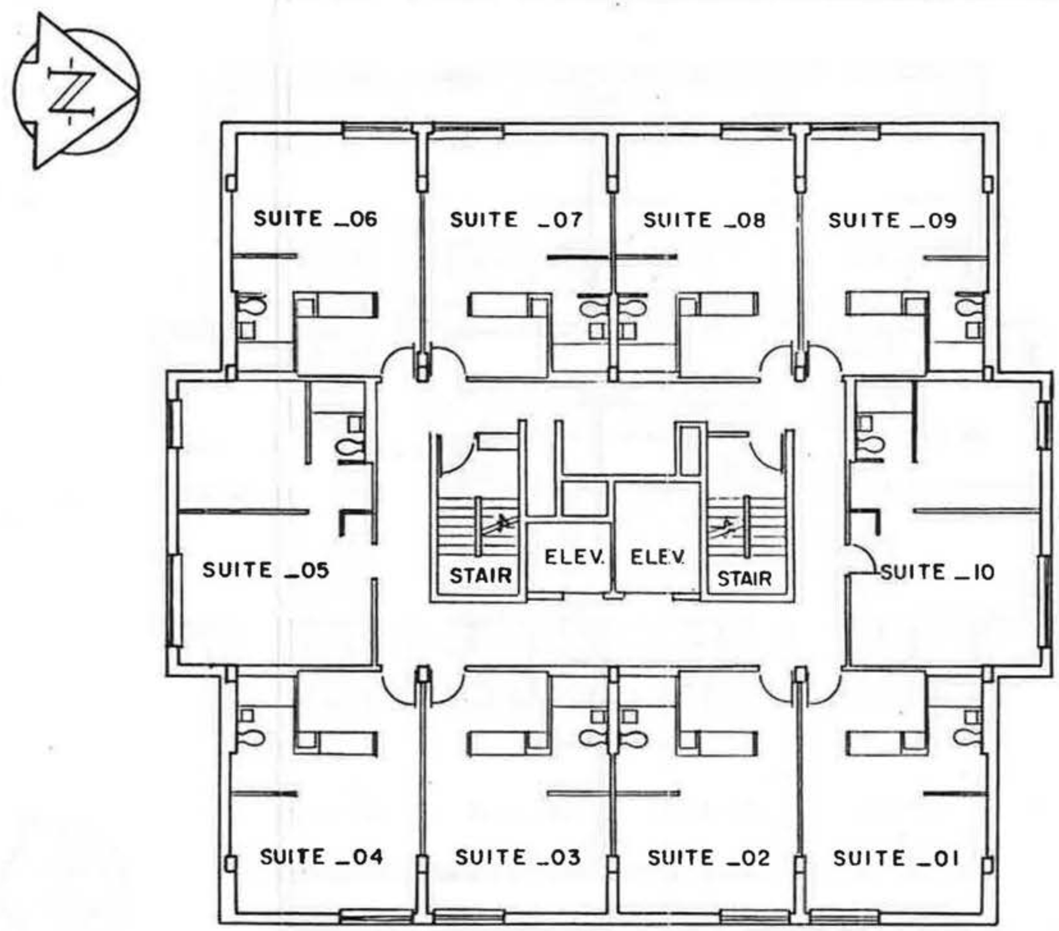
WARDROP ENGINEERING INC.

CLIENT: CANADA MORTGAGE AND HOUSING CORPORATION

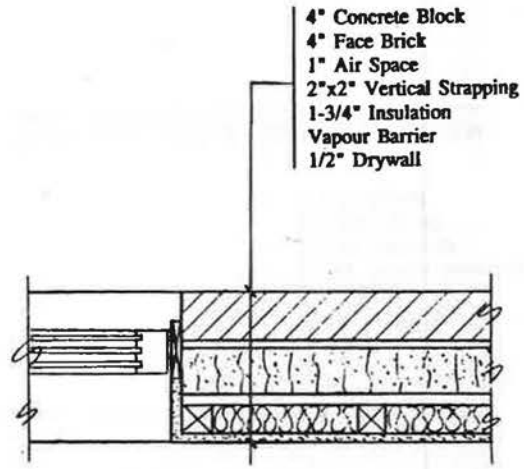
DWG. DESCRIPTION: BUILDING A AIR LEAKAGE MONITORING

| 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 |

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

| 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 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:**

*Suite orientations as viewed from corridor looking into suite.

Q6 - NO PRESSURE MASKING
C = 22.0018
n = 0.5612

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

---

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

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

BOTTOM SUITE PRESSURE MASKED
C = 9.3647
n = 0.6669

Airtightness test results for the Test Suite with simultaneous depressurization.

| 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

| 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

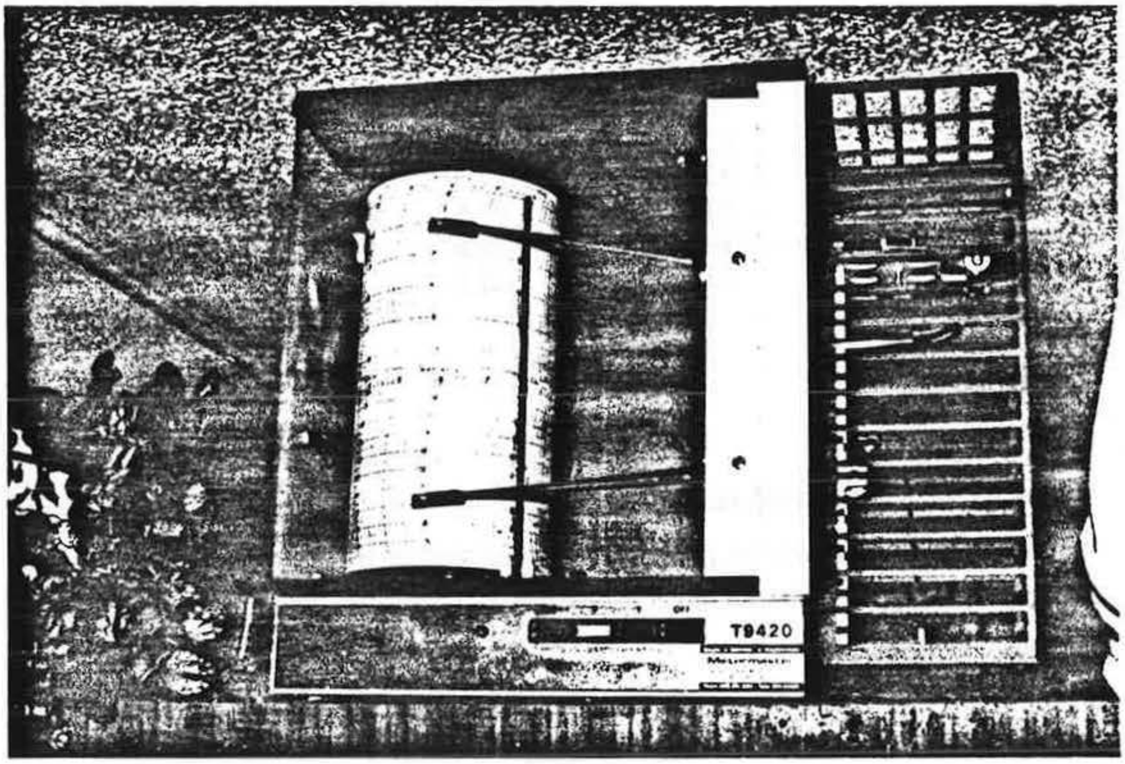
**APPENDIX D**
**AIR QUALITY**
**DATA COLLECTED**

**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**

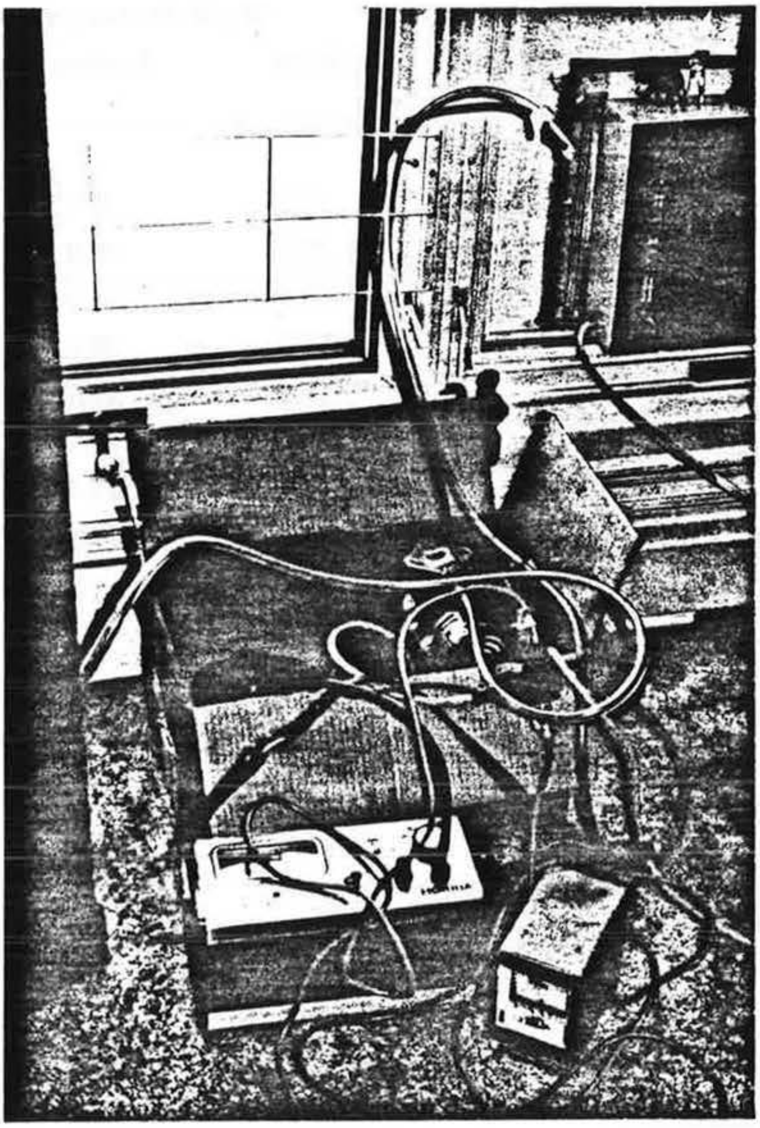
| Suite Number | No. of Readings | Dry Bulb Temperature, °C Mean | Maximum | Minimum |
|---|---|---|---|---|
| 1404 | 81 | 17.0 | 26.0 | 13.0 |
| 1204 | 82 | 18.2 | 26.0 | 15.0 |
| 1104 | 81 | 11.9 | 18.0 | 9.0 |
| 1004 | 72 | 21.3 | 25.0 | 19.5 |
| 606 | 81 | 27.0 | 32.0 | 22.5 |
| 503 | 81 | 14.5 | 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) |

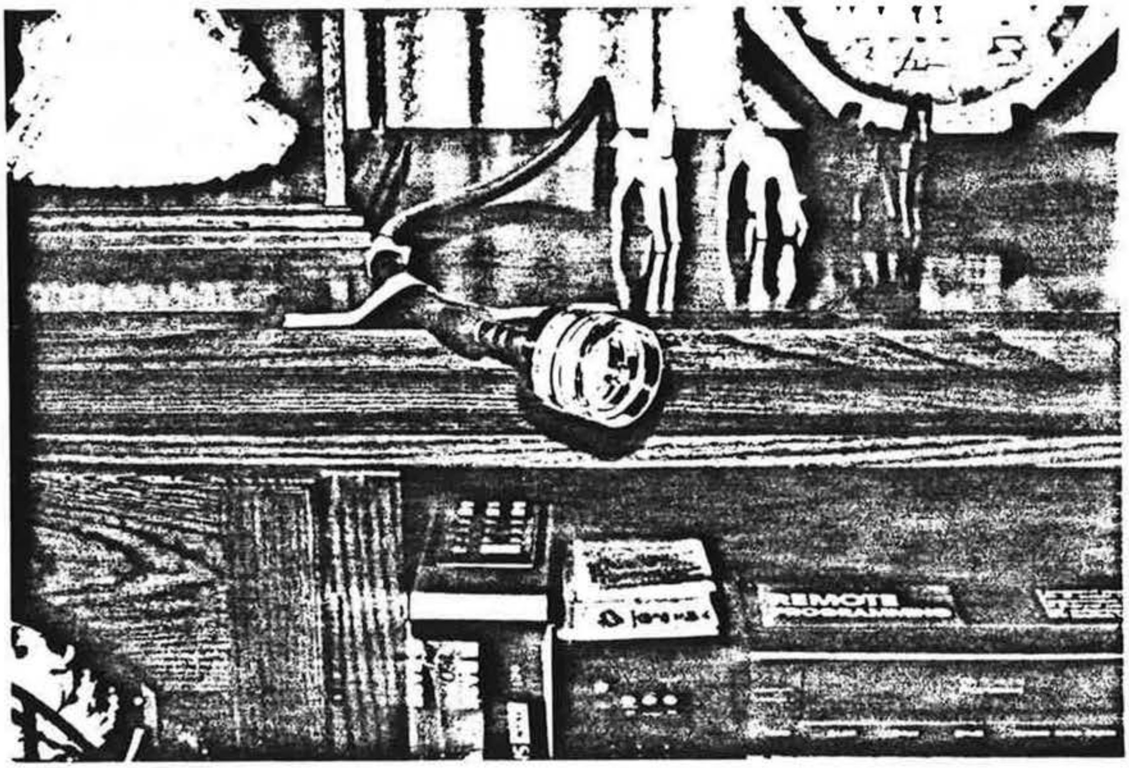
**TABLE 9**
**BUILDINGS A & B**
**BACTERIOLOGICAL TESTING**

| 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/m³ | 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

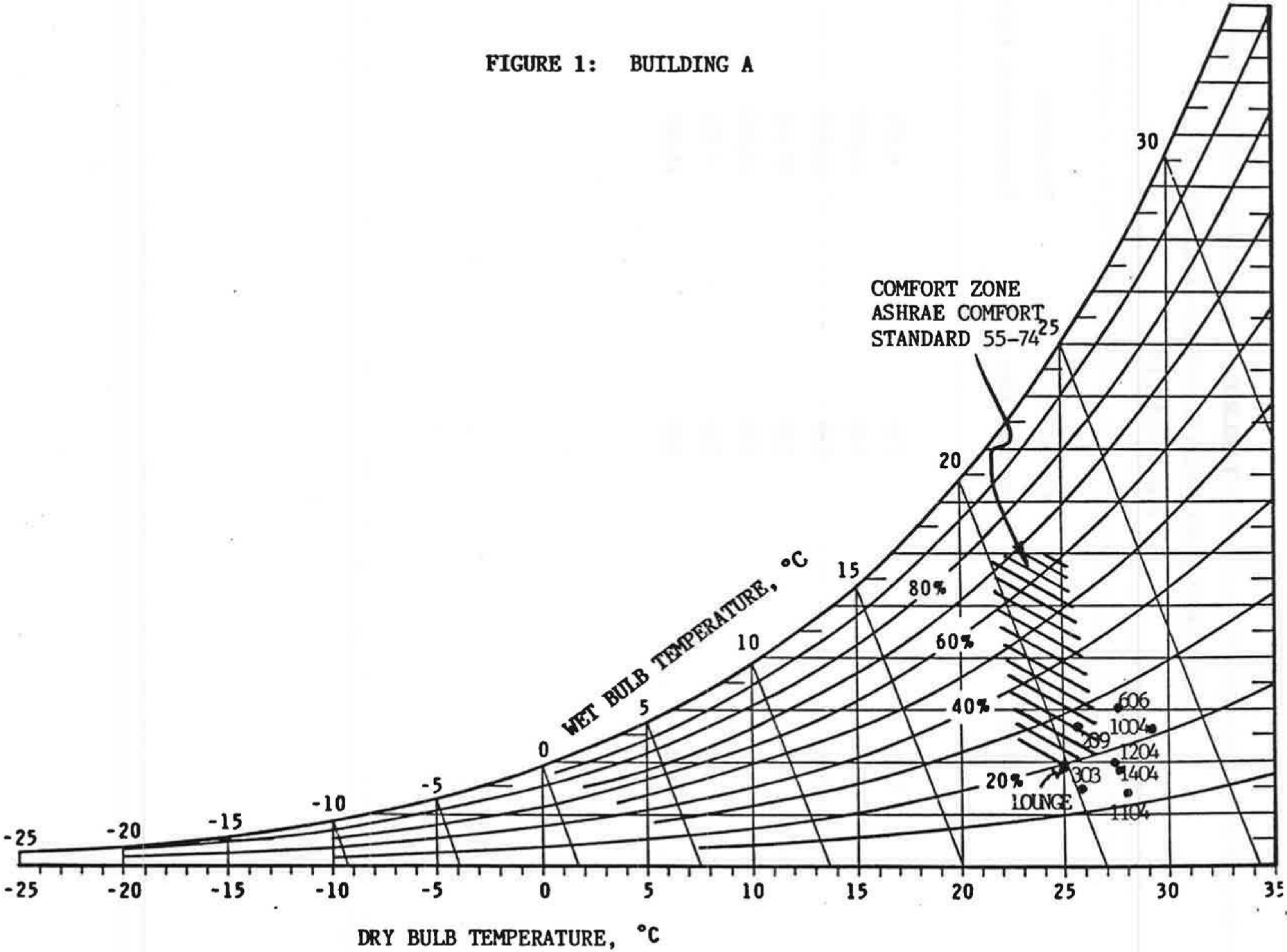
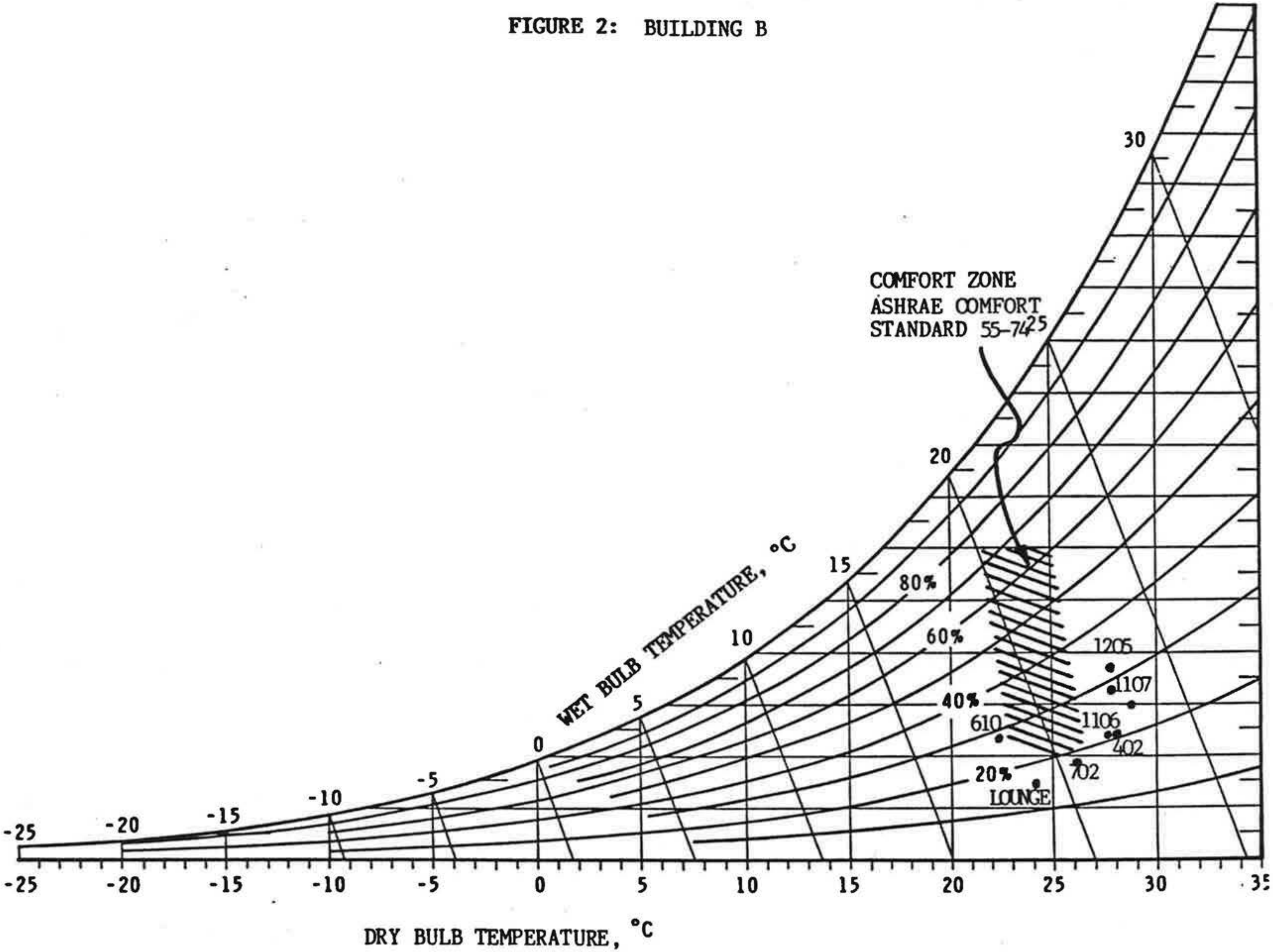


FIGURE 2: BUILDING B



# 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% | 4 did 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 your apartment 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 all survey forms are returned. We would ask that the forms be returned to the building manager upon completion.

**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 |