Air Infiltration Rate of Windows Under Temperature And Pressure Differentials

Prepared For:

CANMET Energy Technology Centre-Ottawa
Buildings Group - Energy Sector
Department of Natural Resources Canada
Ottawa, Ontario, Canada, K1A 0E4
DSS Contract No. 23440-3-9529/01-SQ
October 1995

Prepared By:

Armand Patenaude ing., M.Sc. A.
Air-Ins Inc.
1320, Montée Ste-Julie
Varennes, Québec, Canada, J3X 1P8
Tel: (450) 652-0838: Fax: (450) 652-7588

Scientific Authority:

François Dubros
Buildings Group - Energy Sector
CANMET Energy Technology Centre-Ottawa
Department of Natural Resources Canada
580 Booth Street, 13th Floor
Ottawa, Ontario, Canada, K1A 0E4

Re-Print January 20, 2004

CITATION

Armand Patenaude, R. Jutras and C. Giasson, Air-Ins Inc. *Air Infiltration Rate of Windows Under Temperature and Pressure Differentials.* DSS Contract No. 23440-3-9529/01-SQ. Buildings Group, Energy Sector, CANMET Energy Technology Centre–Ottawa, Department of Natural Resources Canada, Ottawa, Ontario, 1995. (99 pages).

Copies of this report may be obtained through the following:

CANMET Energy Technology Centre (CETC)
Energy Sector
Department of Natural Resources Canada
580 Booth Street, 13th Floor
Ottawa, Ontario, Canada, K1A 0E4

DISCLAIMER

NOTE

Funding for this project was provided by the Federal Panel on Energy Research and Development, Department of Natural Resources Canada (NRCan) and the Industrial Research Assistance Program (IRAP).

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

1.1 INTRODUCTION

The primary objective of this project is to determine the influence of outdoor air temperature and pressure difference acting across different windows on the rate of air infiltration through windows.

The test method used is a modified version of ASTM E1424-91 Standard. The validation of the modified test method has been accomplished by comparing experimental results on 3 windows with another independent laboratory (CANBEST).

The study included tests on 22 windows. The types of window covered include: casements (14), tilt-turn (1), awning (1), horizontal sliders (3) and vertical sliders (3). The different frame and sash materials include: aluminum (5), wood (3), PVC (14).

1.2 RESULTS

Table 1 provides the rate of air infiltration per unit length of crack through the 22 tested windows as a function of the outdoor air temperature and the pressure difference acting across the product.

TABLE 1: RATE OF AIR INFILTRATION THROUGH WINDOWS VERSUS THE OUTDOOR AIR TEMPERATURE AND THE PRESSURE DIFFERENCE

INDOOR AIR TEMPERATURE = 20°C

SUMMARY OF RESULTS

SPECI-MEN NO.	WINDOW TYPE (FRAME & SASH MATERIAL + OTHER WINDOW CHARACTERISTICS)	RATE OF AIR INFILTRATION PER UNIT LENGTH OF CRACK (m^3/h-m)							
		ΔP = 75 Pa				ΔP = 300 Pa			
		OUTDOOR AIR TEMPERATURE (°C)							
		-30	0	20	50	-30	0	20	50
1	Casement (wood frame with PVC cladding, PVC sash, 2 locks, 1 snubber)	1.10	0.65	0.45	0.38	2.14	1.55	1.01	0.94
2	Casement (wood, 2 locks, 1 snubber)	0.25	0.25	0.20	0.27	0.66	0.63	0.52	0.65
3	Casement (wood frame with PVC cladding, PVC sash, 2 locks, 1 snubber)	0.45	0.21	0.18	0.34	1.15	0.78	0.49	0.83
4	Casement (PVC, 2 locks, 1 snubber)	0.18	0.07	0.06	0.11	--	--	--	--
5	Casement (PVC, multipoint locking (3), 1 snubber)	0.12	0.12	0.06	0.11	0.26	0.22	0.15	0.16
6	Casement (PVC, 3 locks, 2 snubbers)	0.23	0.21	0.16	0.16	0.44	0.41	0.34	0.37
7	Casement (PVC, multipoint locking (3), 2 snubbers)	2.84	0.90	0.59	0.54	4.61	1.60	1.29	1.18

SPECI-MEN NO.	WINDOW TYPE (FRAME & SASH MATERIAL + OTHER WINDOW CHARACTERISTICS)	RATE OF AIR INFILTRATION PER UNIT LENGTH OF CRACK (m³/h-m)							
		ΔP = 75 Pa				ΔP = 300 Pa			
		OUTDOOR AIR TEMPERATURE (°C)							
		-30	0	20	50	-30	0	20	50
8	Casement (PVC, multipoint locking (3), 2 snubbers)	1.35	0.28	0.27	0.33	2.26	0.60	0.61	0.60
9	Casement (same as no.8 with a larger bulb weatherstrip)	0.83	0.27	0.24	0.33	1.50	0.59	0.57	0.59
10	Casement (same as no.8, 2 locks, 2 snubbers)	0.58	0.52	0.47	0.55	1.50	1.27	1.12	1.27
11	Casement (Alum., multipoint locking (2))	2.72	1.07	0.82	0.86	3.44	1.54	0.85	0.90
12	Casement (Alum., 2 locks)	0.45	0.37	0.34	0.38	1.17	0.95	0.83	0.86
13	Casement (Alum., multipoint locking (3), 3 snubbers)	0.78	0.39	0.25	0.26	1.26	0.73	0.61	0.55
14	Casement (Frame: Alu., wood and PVC, sash: alu. and PVC)	1.09	0.72	0.58	0.60	2.43	1.78	1.33	1.44
15	Tilt-turn (PVC, 5 locks)	0.58	0.40	0.37	0.42	1.38	1.00	0.97	1.02
16	Awning (wood, 2 locks)	0.43	0.41	0.37	0.41	1.04	0.94	0.84	0.90
17	Horizontal sliding (Alum, 4 moving sashes)	0.61	0.63	0.55	0.56	1.56	1.39	1.32	1.25

SPECI-MEN NO.	WINDOW TYPE (FRAME & SASH MATERIAL + OTHER WINDOW CHARACTERISTICS)	RATE OF AIR INFILTRATION PER UNIT LENGTH OF CRACK (m³/h-m)							
		ΔP = 75 Pa				ΔP = 300 Pa			
		OUTDOOR AIR TEMPERATURE (°C)							
		-30	0	20	50	-30	0	20	50
18	Horizontal sliding (PVC, 1 moving sash)	3.23	2.59	1.89	1.23	10.05	8.80	9.20	7.66
19	Horizontal sliding (PVC, 1 moving sash)	1.17	1.06	1.01	0.93	2.74	2.48	2.41	2.15
20	Vertical sliding (Frame: wood and PVC cladding, 2 tilt-in sashes)	0.62	0.58	0.46	0.48	1.84	1.54	1.26	1.23
21	Vertical sliding (PVC, 1 moving sash)	1.62	1.93	2.85	2.90	6.90	8.47	9.07	10.2
22	Vertical sliding (PVC, 1 tilt-in sash)	9.19	5.83	3.69	6.55	*	*	*	15.1

* Exceeds the maximum measurable air flow rate of 19.47 m³/h-m.

1.3 CONCLUSIONS

1.3.1 TEST METHOD

Except for some minor modifications, the test method provided by the ASTM E1424 proved to be excellent. The required modifications are related to the measurement of extraneous leakage for the test chamber. These modifications are summarized as follows:

a) To reduce the likelihood of large extraneous leakage through the test chamber, the polyethylene film should be firmly attached to the mask wall rather than on the window frame.

b) When measuring the rate of extraneous air leakage through the test chamber, the pressure difference between the outdoor chamber and the cavity formed by the polyethylene film and the window should be equal to the pressure difference for which the extraneous leakage is desired. Perfection being utopic, the testing agency should be allowed to maintain the pressure difference acting across the film equal to or greater than 97% of the pressure difference for which the extraneous leakage is desired.

1.3.2 RATE OF AIR INFILTRATION THROUGH WINDOWS VERSUS OUTDOOR AIR TEMPERATURE AND PRESSURE DIFFERENCE

- Independent of the window type, frame (sash) material and design (number of locking points, snubbers, weatherstripping, etc...), all windows exhibited a change of air leakage rate for outdoor air temperatures other than the base air temperature (T = 20°C).

- For a given window type, the change in air leakage rate versus the outdoor air temperature is intimately tied to the overall design of the product.

- For a given product and pressure difference (75 Pa) with an outdoor air temperature lower than 20°C, the rate of air leakage is always in excess to the value measured at the base temperature.

    - For an outdoor air temperature of 0°C, the rate of air leakage through a given window varies between 1.03 and 2 times the value measured at 20°C.
    - For an outdoor air temperature of -30°C, the rate of air leakage through a given window varies between 1.11 and 5 times the value measured at 20°C.

- For a given pressure difference (75 Pa) and an outdoor air temperature of 50°C, the rate of air leakage through most specimens showed a slight increase or decrease when compared to the value measured at 20°C. The air leakage rate ratio between measurements made at 50°C versus those made at 20°C varies between 0.65 and 1.89.

1.4 RECOMMENDATIONS

To ensure occupant comfort, low energy consumption and an adequate power input from the heating system, the following is recommended:

a) When tested in accordance to the ASTM E1424-91 Standard with an outdoor air temperature of -30°C and an indoor air temperature of 20°C, all windows consisting of one or more sashes (fixed or movable) should meet the existing air leakage rating of the CAN/CSA-A440-M90 Standard (i.e. A1, A2, A3, fixed).

b) Include with the ASTM E1424-91 procedure, the specified modifications with respect to the measurement of extraneous leakage through the test chamber.

2. RÉSUMÉ DE L'ÉTUDE

2.1 INTRODUCTION

Ce projet a pour objectif principal de déterminer l'influence de la température de l'air extérieur et de l'écart de pression entre les ambiances externe et interne sur le taux d'infiltration d'air à travers différentes fenêtres.

La méthode d'essai utilisée est une version modifiée de la norme ASTM E 1424-91. La validation de la méthode d'essai a été réalisée par comparaison des résultats obtenus sur 3 échantillons avec un autre laboratoire indépendant (CANBEST).

L'étude globale porte sur 22 fenêtres. Les différents types de fenêtres soumis à l'essai sont: à battant (14), à auvent (1), oscillo-battante (1), coulissante horizontale (3) et coulissante verticale ou à guillotine (3). Les différentes menuiseries de construction du dormant et des ouvrants sont: aluminium (5), bois (3), PVC (14).

2.2 RÉSULTATS

Le tableau 1 donne les mesures du taux d'infiltration d'air à travers les 22 produits soumis à l'essai, le tout en fonction de la température de l'air extérieur et de l'écart de pression auquel les fenêtres sont assujetties. Les dimensions (largeur x hauteur) des échantillons sont celles dictées par la norme CAN/CSA-A440-M90.

TABLEAU 1: TAUX D'INFILTRATION D'AIR À TRAVERS LES FENÊTRES EN FONCTION DE LA TEMPÉRATURE DE L'AIR EXTÉRIEUR ET DE LA PRESSION DIFFÉRENTIELLE.

$T_{AIR\ INT.}$ = CONSTANTE = 20°C

SOMMAIRE DES RÉSULTATS

ÉCHANTILLON NO.	TYPE DE FENÊTRE (MATÉRIAU DU DORMANT + AUTRES CARACTÉRISTIQUES DE LA FENÊTRE)	TAUX D'INFILTRATION D'AIR PAR UNITÉ DE LONGUEUR DE FENTE (m^3/h-m)							
		ΔP = 75 Pa				ΔP = 300 Pa			
		TEMPÉRATURE DE L'AIR EXTÉRIEUR (°C)							
		-30	0	20	50	-30	0	20	50
1	Battant (cadre de bois rec. PVC, volet de PVC, 2 loquets, 1 butée)	1.10	0.65	0.45	0.38	2.14	1.55	1.01	0.94
2	Battant (bois, 2 loquets, 1 butée)	0.25	0.25	0.20	0.27	0.66	0.63	0.52	0.65
3	Battant (cadre de bois rec. PVC, volet de PVC, 2 loquets, 1 butée)	0.45	0.21	0.18	0.34	1.15	0.78	0.49	0.83
4	Battant (PVC, 2 loquets, 1 butée)	0.18	0.07	0.06	0.11	--	--	--	--
5	Battant (PVC, multipoint - 3, 1 butée)	0.12	0.12	0.06	0.11	0.26	0.22	0.15	0.16
6	Battant (PVC, 3 loquets, 2 butées)	0.23	0.21	0.16	0.16	0.44	0.41	0.34	0.37
7	Battant (PVC, multipoint - 3, 2 butées)	2.84	0.90	0.59	0.54	4.61	1.60	1.29	1.18

ÉCHANTILLON NO.	TYPE DE FENÊTRE (MATÉRIAU DU DORMANT + AUTRES CARACTÉRISTIQUES DE LA FENÊTRE)	TAUX D'INFILTRATION D'AIR PAR UNITÉ DE LONGUEUR DE FENTE (m^3/h-m)							
		ΔP = 75 Pa				ΔP = 300 Pa			
		TEMPÉRATURE DE L'AIR EXTÉRIEUR (°C)							
		-30	0	20	50	-30	0	20	50
8	Battant (PVC, multipoint -3, 2 butées)	1.35	0.28	0.27	0.33	2.26	0.60	0.61	0.60
9	Battant (même que no. 8 mais avec garnitures d'un diamètre plus grand)	0.83	0.27	0.24	0.33	1.50	0.59	0.57	0.59
10	Battant (même que no. 8, 2 loquets, 2 butées)	0.58	0.52	0.47	0.55	1.50	1.27	1.12	1.27
11	Battant (Alu., multipoint - 2)	2.72	1.07	0.82	0.86	3.44	1.54	0.85	0.90
12	Battant (Alu., 2 loquets)	0.45	0.37	0.34	0.38	1.17	0.95	0.83	0.86
13	Battant (Alu., multipoint - 3, 3 butées)	0.78	0.39	0.25	0.26	1.26	0.73	0.61	0.55
14	Battant (Cadre: Alu., bois et PVC Volet: Alu. et PVC)	1.09	0.72	0.58	0.60	2.43	1.78	1.33	1.44
15	Oscillo-battant (PVC, 5 loquets)	0.58	0.40	0.37	0.42	1.38	1.00	0.97	1.02
16	Auvent (bois, 2 loquets)	0.43	0.41	0.37	0.41	1.04	0.94	0.84	0.90
17	Coulissante (Alu., 4 volets mobiles)	0.61	0.63	0.55	0.56	1.56	1.39	1.32	1.25

16

ÉCHANTIL-LON NO.	TYPE DE FENÊTRE (MATÉRIAU DU DORMANT + AUTRES CARACTÉRISTIQUES DE LA FENÊTRE)	TAUX D'INFILTRATION D'AIR PAR UNITÉ DE LONGUEUR DE FENTE (m^3/h-m)							
		ΔP = 75 Pa				ΔP = 300 Pa			
		TEMPÉRATURE DE L'AIR EXTÉRIEUR (°C)							
		-30	0	20	50	-30	0	20	50
18	Coulissante (PVC, 1 volet mobile)	3.23	2.59	1.89	1.23	10.05	8.80	9.20	7.66
19	Coulissante (PVC, 1 volet mobile)	1.17	1.06	1.01	0.93	2.74	2.48	2.41	2.15
20	Guillotine (cadre: bois et PVC, volet: bois rec. PVC, 2 volets mobiles basculants)	0.62	0.58	0.46	0.48	1.84	1.54	1.26	1.23
21	Guillotine (PVC, 1 volet mobile)	1.62	1.93	2.85	2.90	6.90	8.47	9.07	10.2
22	Guillotine (PVC, 1 volet mobile basculant)	9.19	5.83	3.69	6.55	*	*	*	15.1

* Excède 19.47 m^3/h-m (limite maximum mesurable avec notre appareil)

2.3 CONCLUSIONS

2.3.1 MÉTHODE D'ESSAI

A l'exception de quelques légères modifications, la méthode d'essai définie par la norme ASTM E1424-91 est excellente. Les modifications requises s'adressent à la mesure des fuites d'air parasites du caisson d'essai. Les points à modifier sont:

a) Dans le but d'effectuer une mesure adéquate des fuites d'air parasites à travers le caisson d'essai, la fixation du film de polyéthylène devrait se faire sur le masque plutôt que sur le dormant de la fenêtre.

b) Lors de la mesure des fuites d'air parasites à travers le caisson, la mesure de l'écart de pression entre l'ambiance externe et la cavité formée par le film de polyéthylène et la fenêtre, devrait être égale à l'écart de pression pour lequel la mesure des fuites d'air est désirée. A cet effet, il faudra ajouter une prise de pression à travers le film de polyéthylène de façon à mesurer l'écart de pression désiré. La perfection étant utopique, le laboratoire d'essai devrait maintenir l'écart de pression à travers le film égal à l'écart de pression pour lequel la mesure est réalisée plus ou moins 3%.

2.3.2 TAUX D'INFILTRATION D'AIR À TRAVERS LES FENÊTRES EN FONCTION DE LA TEMPÉRATURE DE L'AIR EXTÉRIEUR ET DE LA PRESSION DIFFÉRENTIELLE

- Indépendamment du type de fenêtres, de la menuiserie du dormant et des ouvrants et de la conception globale (nombre de points de fermeture, blocs d'arrêts intermédiaires, dimensions et géométrie des garnitures d'étanchéité, etc...), toutes les fenêtres soumises à l'essai ont subi une variation du taux d'infiltration d'air en fonction de la température d'exposition externe par rapport à la température de référence, soit T = 20°C.
- Pour un type de fenêtre donné (battant, auvent, coulissante) la variation du taux d'infiltration d'air en fonction de la température d'exposition externe est intimement reliée à la conception globale du produit.
- A l'exception d'une fenêtre (échant. no.21), l'ensemble des essais a démontré que pour une pression différentielle donnée (ex.: 75 Pa), le taux d'infiltration d'air augmente avec un abaissement de la température d'exposition externe (T_{EXT} < 20°C).
    - A une température d'exposition externe de 0°C, le taux d'infiltration d'air est de 1.03 à 2.0 fois la valeur mesurée à 20°C.
    - A une température d'exposition externe de -30°C, le taux d'infiltration est de 1.11 à 5.0 fois la valeur mesurée à 20°C.
- Pour une pression différentielle donnée (75 Pa) et pour une température d'exposition externe égale à 50°C, le taux d'infiltration d'air mesuré à travers la plupart des échantillons est légèrement supérieur ou inférieur à la valeur mesurée à 20°C. Le rapport d'infiltration I50°C/I20°C varie entre 0.65 et 1.89.

2.4 RECOMMANDATIONS

Pour assurer le confort des occupants, une faible consommation énergétique et un calcul adéquat de la puissance input requise du système de chauffage, nous recommandons:

a) Que l'ensemble des fenêtres équipées d'un ou de plusieurs châssis (fixe ou mobile) satisfasse la classification actuelle des produits selon la norme CAN/CSA-A440-M90 (i.e. A1, A2, A3, fixe), lorsque testé selon la norme ASTM-E1424-91 avec une température de l'ambiance externe égale -30°C et une température de l'ambiance interne du bâtiment égale à 20°C.

b) D'inclure les modifications requises concernant la fixation du film de polyéthylène et la mesure de l'écart de pression à travers ce film dans la méthode d'essai définie par la norme ASTM E1424-91.

3. INTRODUCTION

3.1 STANDARD PRACTICE

Air leakage through doors, windows and curtain walls is currently measured according to the ASTM E283 standard. The test method measures product hermeticity in ideal conditions, i.e. where the air temperature on both sides of the specimen is 20°C. All Canadian standards (CAN/CSA-A440-M90, CAN/CGSB-82.1-M89), a number of private and government organizations and a number of certification programs use this ASTM reference standard.

Although the tests conducted according to the ASTM E283 standard give results that are reproducible and interesting to a qualified person wishing to compare two or more products, the results cannot be used in defining air leakage rates through these products in the real world, where the components of a building envelope are subjected to summer and winter conditions. In fact, the current data are virtually useless because, where outside temperature is between 20 and 25°C, most of a building's doors and windows are open or ajar.

To predict the actual performance of a building envelope component with respect to the air tightness, it is necessary to evaluate air leakage rates under conditions where the temperature of each component element studied is a realistic representation of summer or winter conditions.

In 1991, the ASTM issued a new test method for determining the rate of air leakage through building envelope components as a function of the temperature and pressure differences to which the specimen is subjected (ASTM E1424-91).

3.2 OBJECTIVES

The primary objective of the project is to determine the influence of the exterior air temperature and the pressure differential between internal and external ambient conditions on the rate of air leakage through windows.

The secondary objectives of the project are to:

- design and develop a test apparatus for determining air leakage through doors and windows as a function of the temperature and pressure differential to which the specimen is subjected;

- determine the air leakage through three window specimens (tight seal, average seal, poor seal) as a function of the temperature and pressure differential to which the specimen is subjected; have the results verified by an independent laboratory;

- determine air infiltration through 10 windows as a function of pressure differential; the 10 specimens are selected to be representative of all sash and frame materials (aluminum, PVC, wood) and window types (casement, tilt-turn, awning and sliding);

- provide results to various organizations likely to have a use for them; the results could be used by the committee drafting the A440 standard in setting acceptable limits of air infiltration at high and low temperatures;

- promote a more satisfactory test method for classifying building envelope components for airtightness.

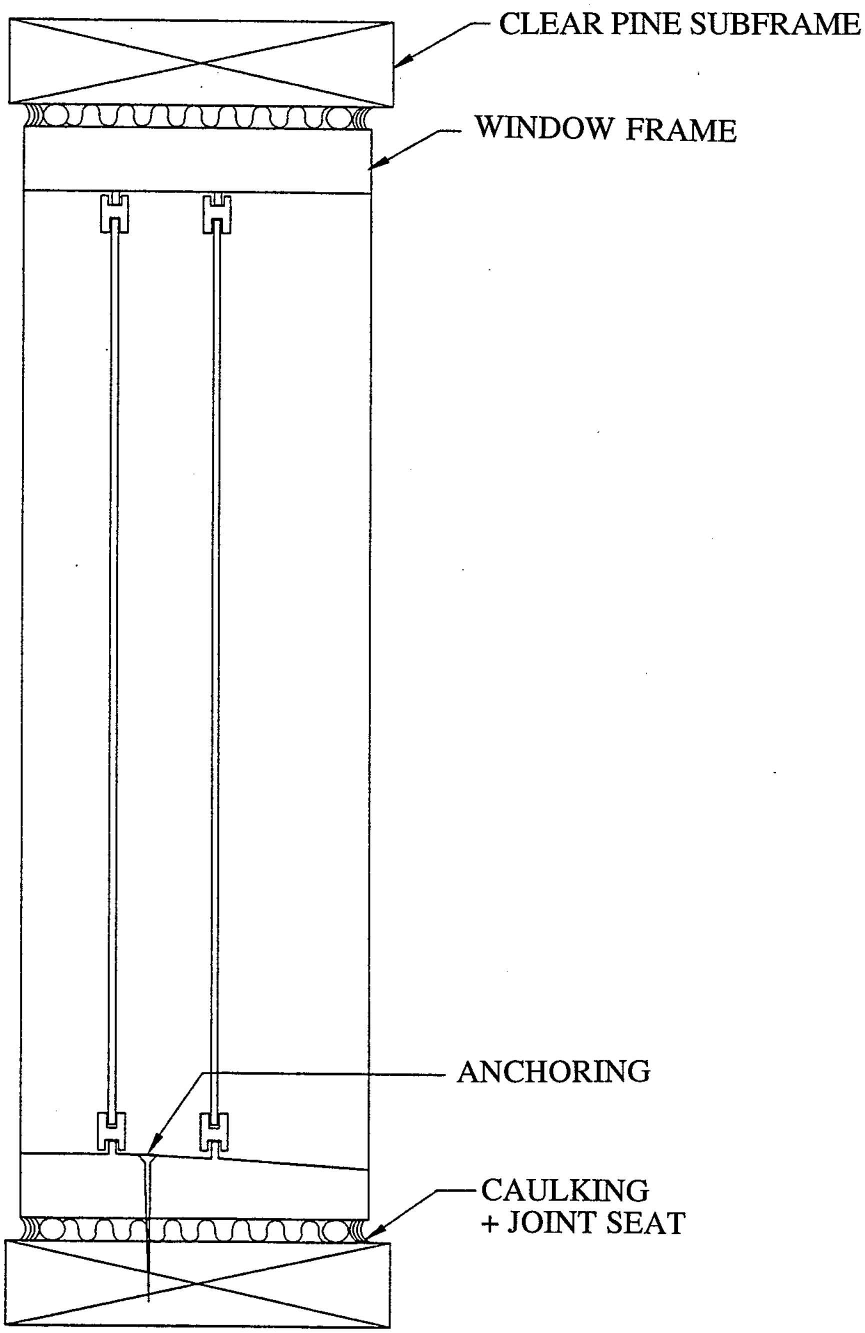
3.3 DESCRIPTION OF TEST SPECIMENS

All specimens were provided free of charge by window manufacturers. We thank them all for their participation in this research and development project.

The exterior window frame dimensions comply with those defined in the CAN/CSA-A440-M90 standard.

All the specimens were installed in clear pine subframes (37 mm x 137 mm) with presealed meeting edges. The method for installing the window frame inside the subframe is specified by the manufacturer (e.g. position and nature of shims, anchoring, fibrous insulation). The play between frame and subframe perimeters is sealed with a bead of caulking applied to the external and internal joints. Figure 1 illustrates the construction method of the frame - subframe assembly.

Table 2 gives the number of specimens and the type of frame and sash materials for each type of window submitted for air leakage testing.



AIR-INS inc.
1320, Mtee Ste-Julie, Varennes, Que., J3X-1P8
Tel.:(514)652-0838 Fax:(514)652-7588

Projet / Project	AIR INFILTRATION WITH TEMPERATURE DIFFERENTIALS
Dessin / Drawing	FRAME-SUBFRAME ASSEMBLY
Dessine par: / Drawn by:	C. GIASSON
Echelle: / Scale:	—
Date:	23/08/95
ver.par: / check.by:	A. PATENAUDE
Dessin no.	1
fichier: / file:	CARLOS//EMR5.DWG

TABLE 2: FRAME/SASH MATERIALS AS A FUNCTION OF WINDOW TYPE

WINDOW TYPE (approximate frame dimensions)	NUMBER OF SPECIMENS	MATERIAL(S)	
		FRAME	SASH
Casement (width = 700 mm height = 1600 mm)	2 1 7 3 1	Wood Wood PVC Alum. Alum. + PVC	PVC Wood PVC Alum. Alum.
Tilt-turn (width = 700 mm height = 1600 mm)	1	PVC	PVC
Awning (width = 1000 mm height = 1000 mm)	1	Wood	Wood
Horizontal slider (width = 1600 mm height = 1000 mm)	1 2	Alum. PVC	Alum. PVC
Vertical slider (width = 1000 mm height = 1600 mm)	1 2	Wood PVC	Wood PVC

Appendix "A" lists the following characteristics for each specimen tested:

- interior and exterior photographs
- window type
- frame material
- sash material
- dimensions
- crack length
- glazing
- number of locking points
- snubber
- short description of sealing system
- anchoring method - frame/subframe

3.4 DESCRIPTION OF TEST APPARATUS

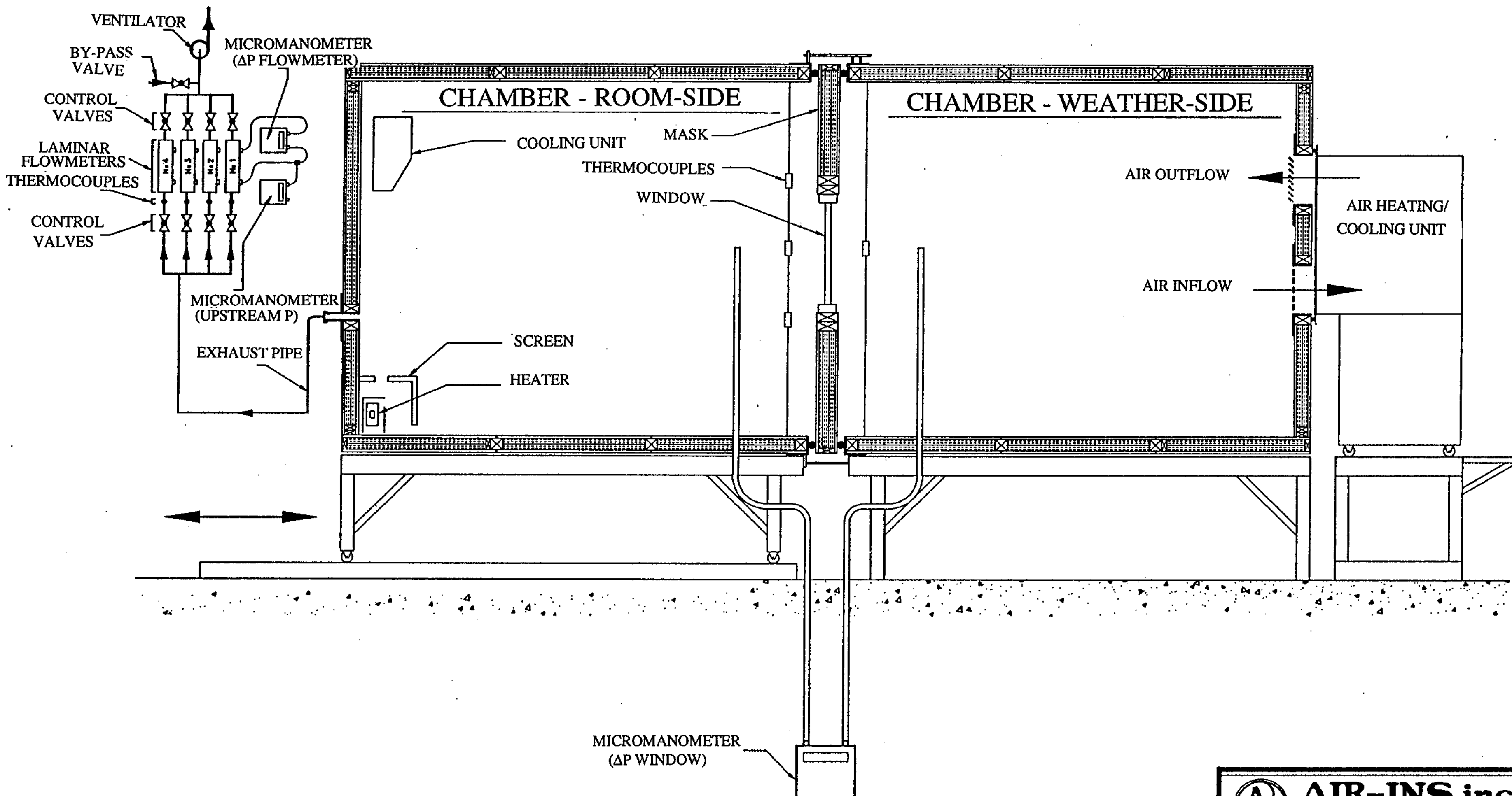
Drawing 2 illustrates the main components of the test apparatus. This includes:

- a mask (insulated wall) that simulates window installation in a typical wall;

- two chambers, the first (movable) representing building interior ambient conditions and the second (fixed) exterior ambient conditions; the mask (including the window) is inserted between the two chambers and the mask/chamber joints are sealed by a combination of weatherstripping and clamps; each chamber is fitted with an air-tight door;

- the chamber representing exterior ambient conditions is equipped with an air conditioning module capable of maintaining a constant air temperature ± 0.5°C; the temperature can be maintained within the -50°C to +60°C range; the air conditioning module maintains constant air circulation (forced convection) around the window;

- the chamber representing the building interior ambient conditions is equipped with a cooling unit and a heater for maintaining air temperature at 20 ± 1°C during the test; air circulation is essentially by natural convection.



AIR-INS inc.
1320, Mtee Ste-Julie, Varennes, Que., J3X-1P8
Tel.:(514)652-0838 Fax:(514)652-7588

Projet / Project	INFILTRATION D'AIR AVEC ÉCART DE TEMPÉRATURE.
Dessin / Drawing	MONTAGE D'ESSAI
Dessiné par: / Drawn by:	C. GIASSON
Echelle: / Scale:	—
Date:	29/06/95
ver.par: / check.by:	A. PATENAUDE
Dessin no.	2
fichier: / file:	CARLOS//EMR2.DWG

- The chamber representing internal ambient conditions is also equipped with an air leakage measuring instrument (flowmeter) for measuring the air leakage rate across the chamber and/or window for a given pressure differential (ΔP window).

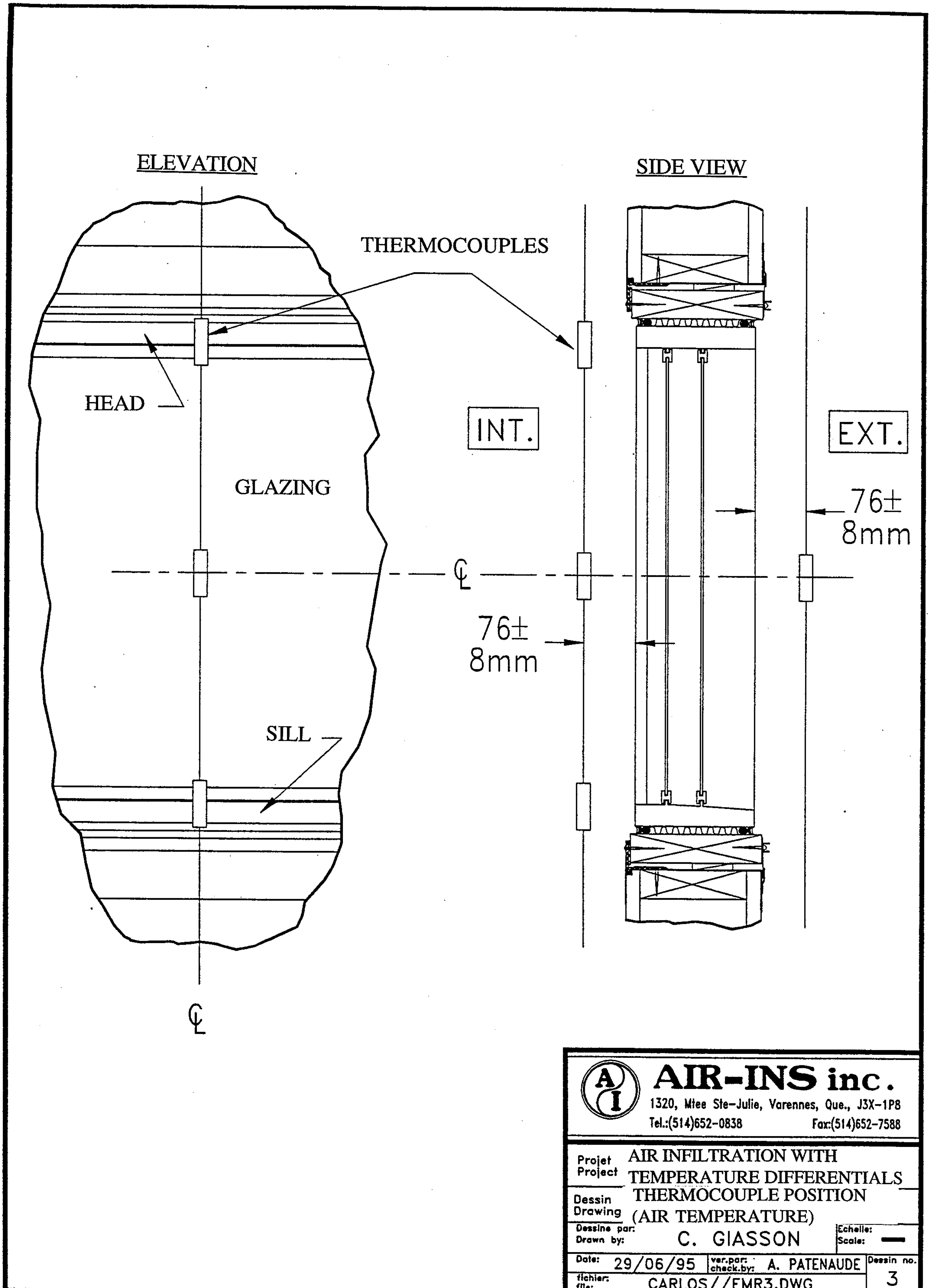
  - Laminar flowmeters are used, with each flowmeter handling a specified range of flow. The technical characteristics of the flowmeters follow.

    - Flowmeter 1: Meriam - Model 50 MJ10-1/2-Type 14
      Range: 0-0.136 m3/h
    - Flowmeter 2: Meriam - Model 50 MJ10-1/2-Type 13
      Range: 0-0.340 m3/h
    - Flowmeter 3: Meriam - Model 50 MH10-1-NT
      Range: 0-13.57 m3/h
    - Flowmeter 4: Meriam - Model 50 MW 20-2
      Range: 0-67.68 m3/h

  - All the temperature sensors are type "T" thermocouples accurate to ± 0.5°C. The sensors used to measure ambient air temperature are fitted with protective shield. Sensor positions are illustrated in drawing 3.

  - All pressure differential measurements across the window and/or flowmeters are recorded by an electronic micromanometer (Model MP6KD- Air Instrument Resources Ltd.).

  - The barometric pressure used in converting measured airflow to standard airflow is supplied by Environment Canada (St-Hubert Station QC).



ELEVATION
SIDE VIEW
THERMOCOUPLES
HEAD
GLAZING
SILL
INT.
EXT.
76±
8mm
76±
8mm
AIR-INS inc.
1320, Mtee Ste-Julie, Varennes, Que., J3X-1P8
Tel.:(514)652-0838
Fax:(514)652-7588
Projet
Project
AIR INFILTRATION WITH
TEMPERATURE DIFFERENTIALS
Dessin
Drawing
THERMOCOUPLE POSITION
(AIR TEMPERATURE)
Dessine par:
Drawn by:
C. GIASSON
Echelle:
Scale:
Date:
29/06/95
ver.par:
check.by:
A. PATENAUDE
Dessin no.
3
fichier:
file:
CARLOS//EMR3.DWG

4. METHODOLOGY

4.1 PREPARATION OF SPECIMEN (WINDOW) AND MASK

Drawing 4 illustrates the method used for installing the subframe - frame assembly with the mask.

(a) A metal angle is used to brace and anchor the specimen subframe to the mask. The subframe/mask joint is sealed with a closed cell foam strip (inside face).

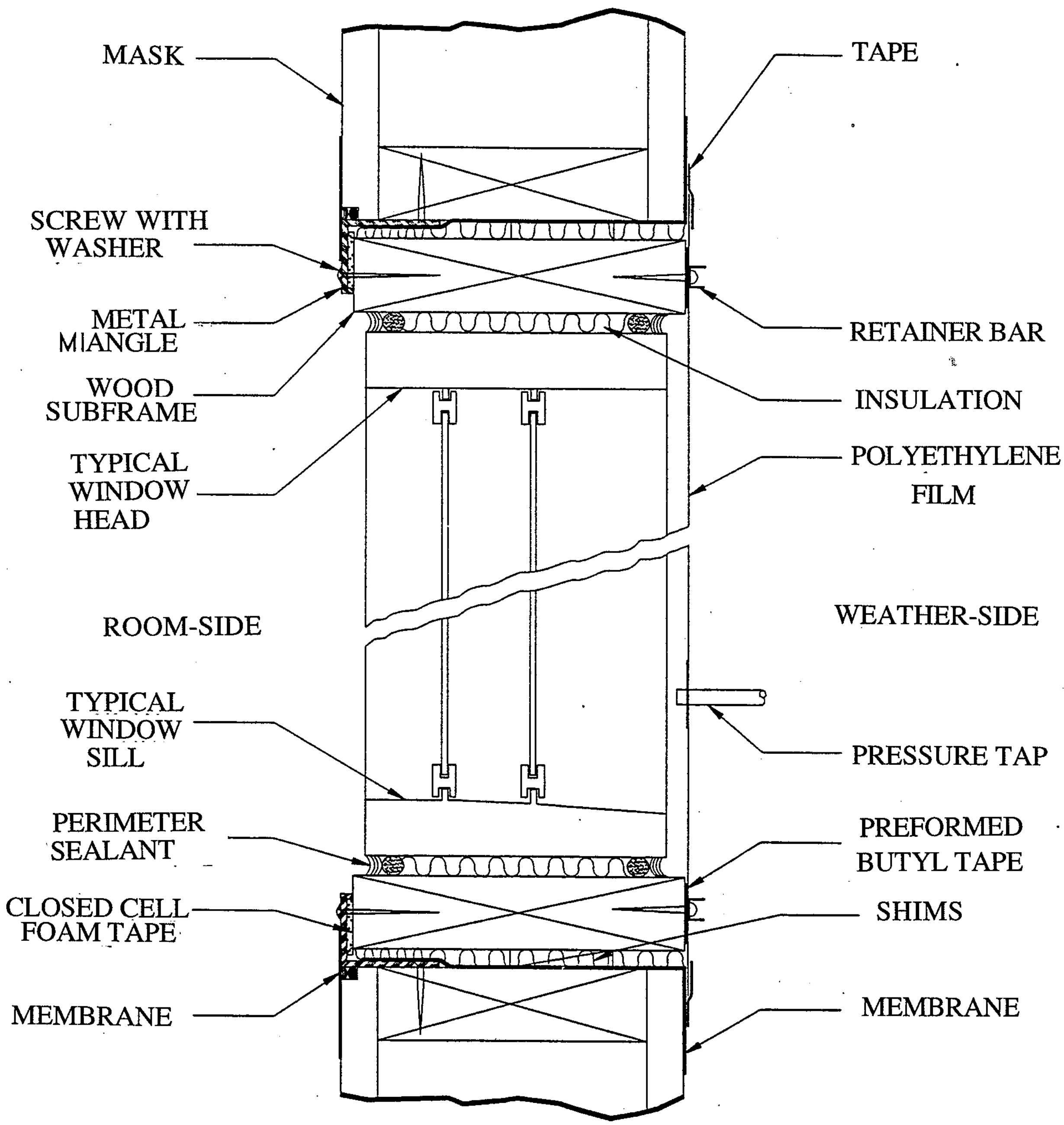
(b) The window is opened and closed five times to ensure that it is operating properly.

(c) The outside face of the subframe/frame/mask assembly is covered with a sheet of polyethylene (0.004 in) held to the wood frame by preformed butyl tape. To guarantee a perfect or near perfect seal at this joint, the film is held by retaining bars installed all around the subframe. The excess polyethylene film is taped to the mask.

(d) A static pressure tap is installed across the polyethylene film to measure the pressure differential between this cavity and the weather-side. It is used for measuring assembly leakage to ensure a satisfactory film - subframe seal.

(e) The mask is then inserted between the two chambers. The seal between the mask and the room-side chamber is achieved using closed cell neoprene compression packing. An inflatable seal installed between the weather-side chamber and the mask seals this joint and provides clamping force.

(f) Five type "T" thermocouples are attached to the designated interior surface of the window, in accordance with the ASTM E-1424-91 standard. Drawing 5 shows the thermocouple positions for the various window types.

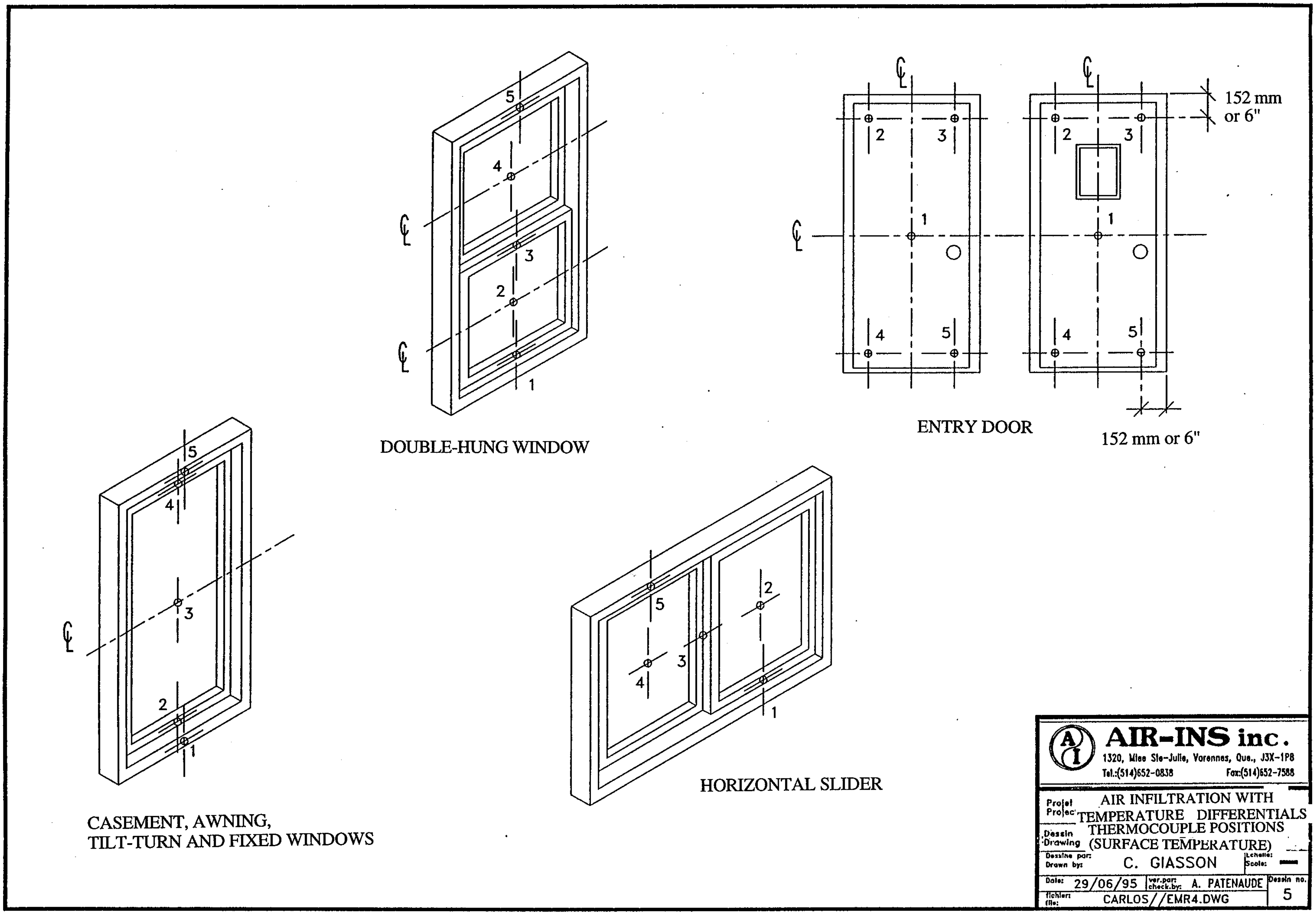


AIR-INS inc.
1320, Mtee Ste-Julie, Varennes, Que., J3X-1P8
Tel.:(514)652-0838 Fax:(514)652-7588

Projet / Project: AIR INFILTRATION WITH TEMPERATURE DIFFERENTIALS

Dessin / Drawing: WINDOW INSTALLATION

Dessine par: / Drawn by: C.GIASSON		Echelle: / Scale: —	
Date: 29/06/95	ver.par: / check.by: A. PATENAUDE	Dessin no.	
fichier: / file: CARLOS//EMR1.DWG		4	


152 mm
or 6"
152 mm or 6"
ENTRY DOOR
DOUBLE-HUNG WINDOW
HORIZONTAL SLIDER
CASEMENT, AWNING,
TILT-TURN AND FIXED WINDOWS
AIR-INS inc.
1320, Mtee Ste-Julie, Varennes, Que., J3X-1P8
Tel.:(514)652-0838 Fax:(514)652-7588
Projet Project: AIR INFILTRATION WITH TEMPERATURE DIFFERENTIALS
Dessin Drawing: THERMOCOUPLE POSITIONS (SURFACE TEMPERATURE)
Dessine par: Drawn by: C. GIASSON
Echelle: Scale:
Date: 29/06/95
ver.par: check.by: A. PATENAUDE
Dessin no. 5
fichier: file: CARLOS//EMR4.DWG

4.2 TEST PROCEDURE

The tests were conducted in accordance with the ASTM E-1424-91 standard.

During a given test, the air temperature in the room-side chamber is maintained at a constant 20°C, while the air temperature in the weather-side chamber is maintained constant at one of the following temperatures: 20°C (base), -30°C, 0°C and 50°C. For each possible combination (i.e. 20°C/20°C, 20°C/-30°C, 20°C/0°C and 20°C/50°C), the procedure is as follows.

(a) Condition specimen (with polyethylene film installed on weather-side) at zero pressure differential (± 3 Pa) across the mask.

(b) When thermal equilibrium conditions have been achieved, measure air infiltration rates across room-side chamber (T = 20°C) and mask at pressure differentials of 75 Pa and 300 Pa.

(c) Recondition specimen (without polyethylene film) as in (a) above and zero pressure differential (± 3 Pa) across the mask.

(d) When thermal equilibrium conditions have been achieved, measure total air infiltration rate (window + mask + room-side chamber) at pressure differentials of 75 Pa and 300 Pa.

(e) Calculate air infiltration rate across the specimen.

Detailed descriptions of these five steps follow.

4.2.1. CONDITION SPECIMEN WITH POLYETHYLENE FILM

The specimen covered by polyethylene film is conditioned at one of the above-mentioned temperature differentials (e.g. 20°C/-30°C) until thermal equilibrium is achieved.

The thermal equilibrium of a specimen is achieved when the surface temperature indicated by each of the five thermocouples (drawing 5) varies no more than 1°C in five consecutive readings at 10-minute intervals. The difference in static pressure between the two test chambers is kept as low as possible during conditioning, i.e. ± 3 Pa. The relative humidity of the air in the room-side chamber is maintained fairly low to avoid surface condensation on the test window.

Ambient air temperatures at the centre of the specimen are controlled to within ± 1.0°C of the nominal value required for a specific test.

Comment:

Although the ASTM E1424-91 standard stipulates that the interior ambient air temperature be measured at three points (drawing 4), no specific instructions are given for establishing the resulting temperature. For purposes of this study, the air temperature used is the temperature measured at the mid-point of the specimen's vertical axis.

4.2.2 MEASURE AIR INFILTRATION RATE ACROSS CHAMBER (ROOM-SIDE) AND MASK (Qm)

When thermal equilibrium has been achieved and maintained for at least two hours, assembly leakage is measured.

All fans in the room-side and weather-side chambers are stopped. The weather-side chamber is opened to the atmosphere and the interior chamber is sealed.

An airflow control/measurement system is used to depressurize the interior chamber to maintain the static pressure differential between the two chambers at 75 Pa.

Using the pressure tap installed through the polyethylene film, the static pressure differential between the room-side and the weather-side of the window is checked to ensure that it is equal to or less than 2 Pa. This condition ensures that the polyethylene film is properly installed and air infiltration through the window is almost nil. If the static pressure differential measured across the window is greater than 2 Pa, the polyethylene film must be carefully inspected and any fault corrected until the static pressure differential is equal to or less than 2 Pa.

The ASTM E1424-91 standard stipulates that, for a given pressure differential, air leakage must be measured within five minutes. Also, the ambient temperatures in the weather-side and room-side chambers must not vary by more than 3°C. The standard states that when these conditions are not met the specimen must be reconditioned to achieve thermal equilibrium.

Comment:

In practice, when the measured air leakage is small (well-sealed assembly), five minutes is not long enough to stabilize the pressure differential; 10 to 15 minutes are often required. When a small assembly leakage is measured, we believe that test duration (five to 15 minutes) has no influence on air infiltration rate because the only possible leakage is across the chamber and the mask.

However, conditioning should be repeated if the variation in ambient air temperature on either side is more than 3°C.

When the conditions defined above are met and the pressure differential is stable (e.g. 75 Pa), the air infiltration rate across the chamber (room-side) and mask is measured. The air volume flow rate (Qm_{act}) is then converted to standard conditions (Qm(std)), i.e. to T = 20°C and P = 101.3 kPa.

To establish the air infiltration rate with a pressure differential of 300 Pa, the room-side chamber + mask assembly is reconditioned and the test procedure repeated.

4.2.3 CONDITION SPECIMEN (NO POLYETHYLENE FILM)

The polyethylene film is removed and the specimen is reconditioned using the procedure specified in section 4.2.1 until thermal equilibrium is again achieved.

4.2.4 MEASURE TOTAL CHAMBER (ROOM) + MASK + SPECIMEN AIR INFILTRATION (Qt)

The total air infiltration rate (Qt) for a given pressure differential (e.g. 75 Pa) is measured using the procedure specified in section 4.2.2, with the following differences:

- the details regarding the polyethylene film do not apply;
- the five-minute limit for measurement of airflow (Qt_{act}) does apply.

As before, the air volume flow rate measured (Qt_{act}) is converted to standard conditions (Qt_{std}), i.e. to T = 20°C and P = 101.3 kPa.

To establish the air infiltration rate with a pressure differential of 300 Pa, the (2) chambers + mask + specimen assembly is reconditioned and the same test procedure repeated.

4.2.5 CALCULATION OF AIR INFILTRATION RATE THROUGH SPECIMEN (Q_w)

For a given pressure differential, the air infiltration rate across the window (Qw_{std}) is obtained by calculating the difference between total leakage (Qt_{std}) and assembly leakage (Qm_{std}), giving the following equation:

$$Qw_{std} = Qt_{std} - Qm_{std}$$

The air infiltration rate across the window (Qw_{std}) is then related to unit sash crack length, by dividing Qw_{std} by the sash crack length (L) for the window in question. Sash crack length is defined as in CAN/CSA-A440-M90.

5. RESULTS

5.1 AIR INFILTRATION RATES

Table 3 gives the air infiltration rate measurements for the 22 products tested as a function of the outside air temperature and the pressure differential to which the windows are subjected. The nominal dimensions (height x width) of the frame of each window are those specified by the CAN/CSA-A440-M90 standard.

TABLE 3: RATE OF AIR INFILTRATION THROUGH WINDOWS AS A FUNCTION OF OUTDOOR AIR TEMPERATURE AND PRESSURE DIFFERENCE

$T_{AIR\ INT.}$ = CONSTANT = 20°C

SUMMARY OF RESULTS

SPECIMEN NO.	WINDOW TYPE (FRAME + SASH MATERIAL + OTHER WINDOW CHARACTERISTICS)	RATE OF AIR INFILTRATION PER UNIT LENGTH OF CRACK (m3/h-m)							
		ΔP = 75 Pa				ΔP = 300 Pa			
		OUTDOOR AIR TEMPERATURE (°C)							
		-30	0	20	50	-30	0	20	50
1	Casement (wood frame with PVC cladding, PVC sash, 2 locks, 1 snubber)	1.10	0.65	0.45	0.38	2.14	1.55	1.01	0.94
2	Casement (wood, 2 locks, 1 snubber)	0.25	0.25	0.20	0.27	0.66	0.63	0.52	0.65
3	Casement (wood frame with PVC cladding, PVC sash, 2 locks, 1 snubber)	0.45	0.21	0.18	0.34	1.15	0.78	0.49	0.83
4	Casement (PVC, 2 locks, 1 snubber)	0.18	0.07	0.06	0.11	--	--	--	--
5	Casement (PVC, multipoint locking (3), 1 snubber)	0.12	0.12	0.06	0.11	0.26	0.22	0.15	0.16
6	Casement (PVC, 3 locks, 2 snubbers)	0.23	0.21	0.16	0.16	0.44	0.41	0.34	0.37
7	Casement (PVC, multipoint locking (3), 2 snubbers)	2.84	0.90	0.59	0.54	4.61	1.60	1.29	1.18
8	Casement (PVC, multipoint locking (3), 2 snubbers)	1.35	0.28	0.27	0.33	2.26	0.60	0.61	0.60
9	Casement (same as 8 but with larger bulb weather strip)	0.83	0.27	0.24	0.33	1.50	0.59	0.57	0.59
10	Casement (same as 8, 2 locks, 2 snubbers)	0.58	0.52	0.47	0.55	1.50	1.27	1.12	1.27
11	Casement (Alum., multipoint locking (2))	2.72	1.07	0.82	0.86	3.44	1.54	0.85	0.90
12	Casement (Alum., 2 locks)	0.45	0.37	0.34	0.38	1.17	0.95	0.83	0.86
13	Casement (Alum., multipoint locking (3), 3 snubbers)	0.78	0.39	0.25	0.26	1.26	0.73	0.61	0.55
14	Casement (Alum. ext. and PVC int., 2 locks, 2 snubbers)	1.09	0.72	0.58	0.60	2.43	1.78	1.33	1.44
15	Tilt-turn (PVC, 5 locks)	0.58	0.40	0.37	0.42	1.38	1.00	0.97	1.02

SPECIMEN NO.	WINDOW TYPE (FRAME + SASH MATERIAL + OTHER WINDOW CHARACTERISTICS)	RATE OF AIR INFILTRATION PER UNIT LENGTH OF CRACK (m3/h-m)							
		ΔP = 75 Pa				ΔP = 300 Pa			
		OUTDOOR AIR TEMPERATURE (°C)							
		-30	0	20	50	-30	0	20	50
16	Awning (wood, 2 locks)	0.43	0.41	0.37	0.41	1.04	0.94	0.84	0.90
17	Horizontal slider (Alum., 4 movable sashes)	0.61	0.63	0.55	0.56	1.56	1.39	1.32	1.25
18	Horizontal slider (PVC, 1 movable sash)	3.23	2.59	1.89	1.23	10.05	8.80	9.20	7.66
19	Horizontal slider (PVC, 1 movable sash)	1.17	1.06	1.01	0.93	2.74	2.48	2.41	2.15
20	Vertical slider (frame: wood and PVC; sash: wood and PVC cladding, 2 tilt-in sashes)	0.62	0.58	0.46	0.48	1.84	1.54	1.26	1.23
21	Double-hung (PVC, 1 movable sash)	1.62	1.93	2.85	2.90	6.90	8.47	9.07	10.2
22	Double-hung (PVC, 1 tilt-in sash)	9.19	5.83	3.69	6.55	*	*	*	15.1

* Exceeds 19.47 m3/h-m (maximum measurable with our instruments)

5.2 OBSERVATIONS

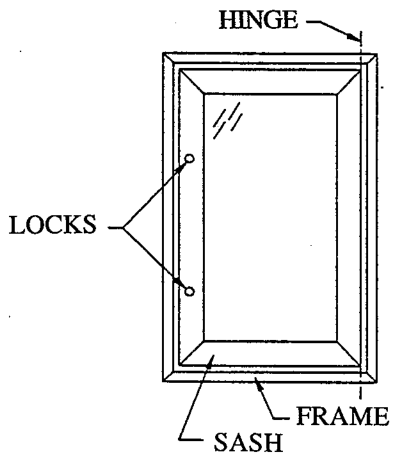
The observations made during the tests at different internal and external ambient air temperatures are aimed mainly at differential movement between window sash(es) and frame. The observations specific to each product are given in Appendix B.

The observations for each type of window may be summarized as follows.

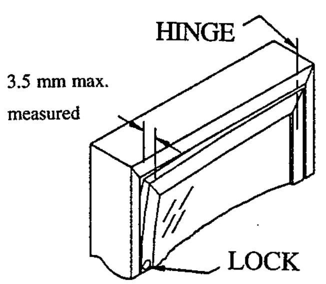
(a) Casement window

- Low exterior temperature
  - exterior warping of upper and lower sash frame corners (lock side) in relation to frame (see drawing below);
  - amplitude of differential movement varies as a function of product design (nature of materials, profile rigidity, number and position of locking points);
  - maximum observed amplitude is 3.5 mm (specimen 11 at -30°C);
  - photographs 1 to 3 illustrate the amplitude of observed warping.

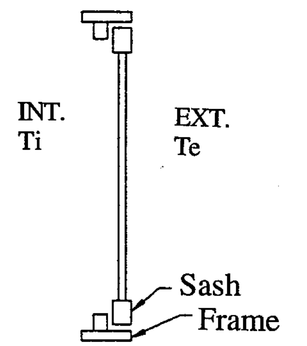
ELEVATION



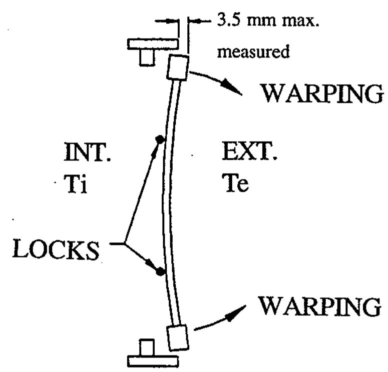
EXTERIOR VIEW

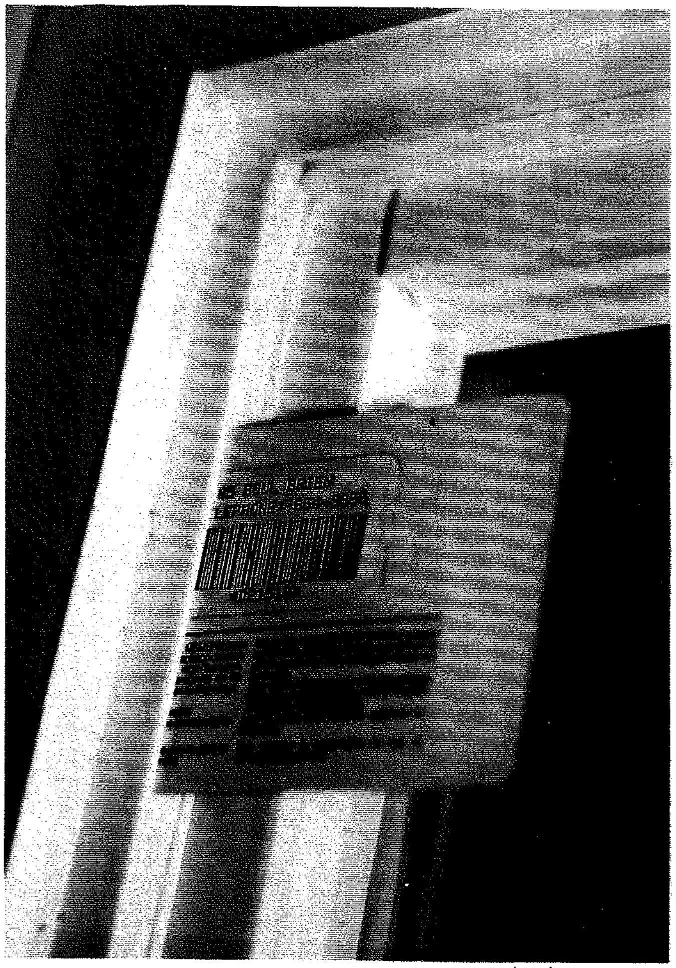


SIDE VIEW (Ti = Te)

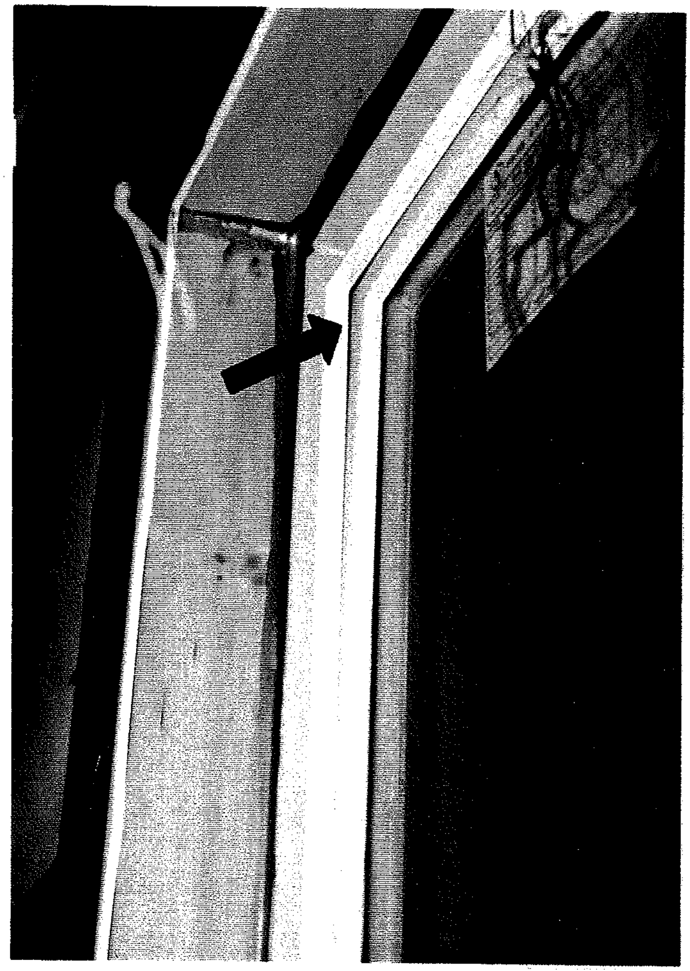


LOCK SIDE VIEW (Ti > Te)





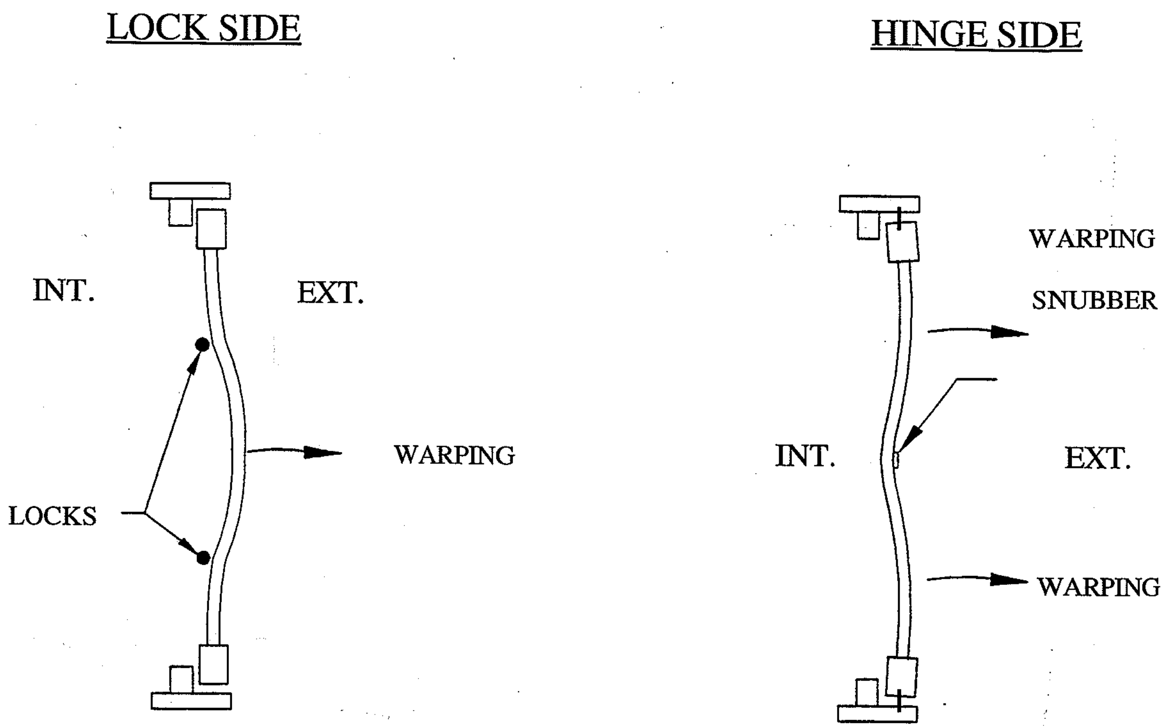
Photograph 1: Sash warping, upper left corner (specimen 8)



Photograph 3: Sash warping, upper left corner (specimen 7)

Photograph 2: Sash warping, lower left corner (specimen 8)

- High exterior temperature
  - exterior warping of sash stiles between stile/frame joints (see drawings below).



  - amplitude of differential movement varies as a function of product design (nature of materials, profile rigidity, number and position of locks and intermediate snubbers);
  - maximum amplitude observed is 2.2 mm on lock side and 1.4 mm on hinge side.

(b) Tilt-turn window

  - No measurable differential movement as a function of differences in exposure temperature.

(c) Awning window

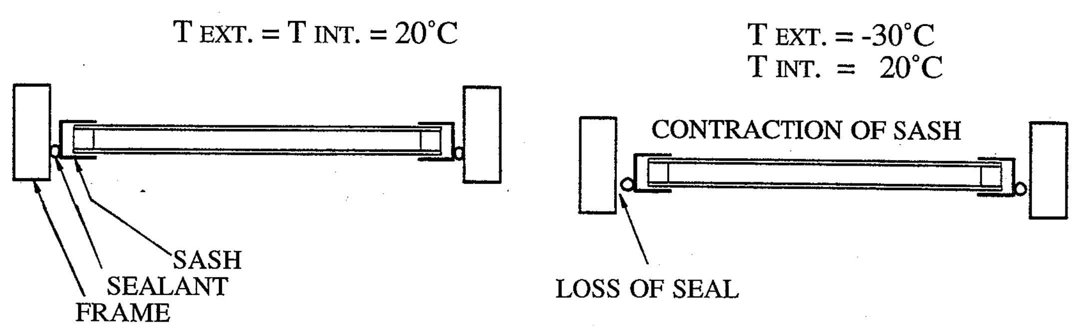
No measurable differential movement as a function of differences in exposure temperature.

(d) Horizontal slider

No apparent differential movement observed, with the exception of specimen 18 in which there is slight curvature of meeting rails in relation to sash stiles (1 to 1.5 mm).

(e) Double-hung window

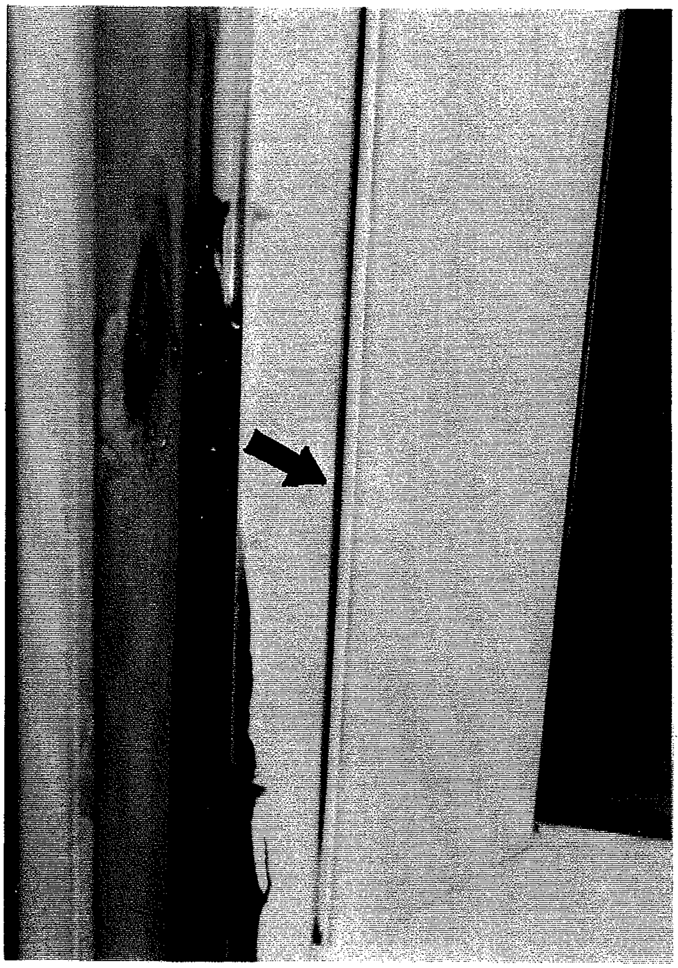
Double-hung windows with tilt-in sash are more subject to loss of perimeter seal at low temperatures. In some products, contraction of the sash with respect to the frame may result in loss of contact between weather strip and adjacent member. The drawing below illustrates these differential movements, and photographs 4 and 5 show the effect thereof.



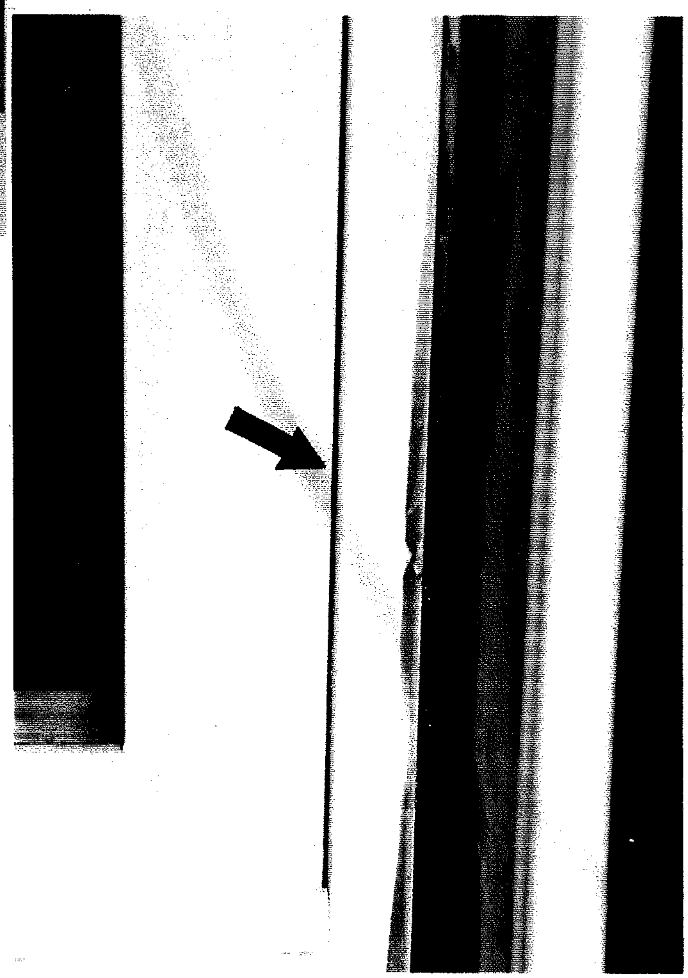
6. VERIFICATION OF TEST METHOD

6.1 INTRODUCTION

In order to verify the reproducibility of the experimental results obtained with some specimens for given boundary conditions, some tests were repeated by an independent testing laboratory (CANBEST).



Photograph 4:
Loss of contact between weather strip and frame jamb - left side (specimen 22)



Photograph 5:
Loss of contact between weather strip and frame jamb - right side (specimen 22).

6.2 SPECIMEN SELECTION

The specimens were selected to represent the complete range of possible air infiltration rates for Canadian windows (tight seal, average seal, poor seal). One specimen (sash/frame material PVC) was selected to check whether an increase in surface temperature ($T_{EXT.} \approx$ 50°C) has any impact on the air seal characteristic after testing by the first laboratory (Air-Ins Inc.). Table 4 lists the specimens selected for the test method verification defined by the ASTM E1424-91 standard (slightly modified).

TABLE 4: SPECIMEN SELECTION

SPECIMEN NO.	WINDOW TYPE
5	Casement (PVC)
13	Casement (Alum.)
16	Awning (Wood)

The test conditions selected for comparison of experimental results are:

- $\Delta P = 75$ Pa, $T_{int.} = 20°C$ and $T_{ext.} = -30°C$
- $\Delta P = 300$ Pa, $T_{int.} = 20°C$ and $T_{ext.} = -30°C$

6.3 RESULTS

Table 5 gives the air infiltration rate measured by each laboratory across the three specimens for the above boundary conditions.

TABLE 5: COMPARISON OF MEASURED AIR INFILTRATION RATES
$T_{AIR\ INT.}$ = 20°C

SPECIMEN NO.	WINDOW TYPE	RATE OF AIR INFILTRATION PER UNIT LENGTH OF CRACK (m3/h-m)			
		ΔP = 75 Pa $T_{AIR\ EXT.}$ = -30°C		ΔP = 300 Pa $T_{AIR\ EXT.}$ = -30°C	
		AIR-INS INC.	CANBEST*	AIR-INS INC.	CANBEST*
5	Casement (PVC)	0.12	0.12	0.26	0.301
13	Casement (Alum.)	0.78	0.72	1.26	1.31
16	Awning (Wood)	0.43	0.47	1.04	1.11

* The test report issued by CANBEST is included as Appendix "C".

6.4 ANALYSIS OF VERIFICATION METHOD

Although the test results produced by the two laboratories demonstrate excellent reproducibility (± 20% for low air infiltration rates and ± 10% for average air infiltration rates), the verification method used can produce widely varying results.

The main factors that can influence the results of a series of tests conducted by two laboratories are:

- effect of temperature on material behaviour;
- effect of temperature on assembly behaviour (e.g. PVC versus aluminum sash);
- effect of variation in relative humidity on water content of hygroscopic materials (wood);
- specimen transportation between the two laboratories;
- test procedure used in each laboratory.

(a) Effect of temperature on material behaviour

Whereas a variation in temperature of wood or aluminum produces reversible contraction or expansion, the same is not true of thermoplastics. Surface heating of PVC (a thermoplastic) has significant consequences on the physical/mechanical characteristics of the material. Locally, under the effect of a temperature increase, the material swells and softens (reduction in elasticity module). The longitudinal stress induced by the extrusion process are released, producing contraction of the exterior surface layers, while centre areas and interior surfaces of the extrusions, which are colder, are little affected. The resulting phenomenon, known as differential thermal movement, may generate concavity in the extrusions and permanent sagging in sash and frame materials. Where a thermoplastic material is used, the effect may change extrusion length and height.

(b) Effect of temperature on assembly behaviour

A change in temperature of a composite assembly (e.g. aluminum/PVC) made of materials with different coefficients of thermal expansion creates shear stress at joints between the materials. This can lead to partial or complete separation along the longitudinal axis of the assembly, thus reducing assembly rigidity.

(c) Effect of variation in relative humidity of ambient air

An increase in the relative humidity of ambient air increases the water content of a hygroscopic material (wood) and the material expands. Conversely, a drop in the relative humidity of the ambient air has the opposite effect, i.e. the material contracts. The resulting phenomenon can decrease/increase the window airtightness.

(d) Transportation of specimens

Although the specimens were prepared as carefully as possible, the window handling between test laboratories can change the product airtightness properties.

(e) Test procedure used by the laboratories

(1) Coefficient of surface film on outside surface of specimen

The ASTM E1424-91 standard does not stipulate the coefficient of the film to be maintained on the outside surface of the specimen.

The test assembly developed by Air-Ins Inc. maintains constant air movement (forced convection) on the weather-side, whereas the test assembly developed by CANBEST uses a constant film coefficient (22 W/m2 - °C) on the outside surface of the specimen.

This difference in the test method modifies the outside surface temperature of the window elements, producing differences in sash element warping and air infiltration rate.

Of all the factors that can influence the test results, this is certainly the most significant.

Recommendation

To ensure result reliability for different test laboratories, the test method should specify a standard coefficient for the film installed on the outside surface of the specimen.

(2) Preconditioning of hygroscopic frame and sash materials

Changes in dimensions of wooden elements are strongly influenced by ambient relative humidity.

This factor was not considered by the laboratories in the verification procedure.

Recommendation

To ensure result reliability between test laboratories, the test method should include a period of preconditioning (e.g. T = 20°C and HR = 30% for one week prior to testing) for hygroscopic frame and sash materials..

(3) Conditioning of hygroscopic frame and sash material during testing

Although the two test laboratories made sure there was no surface condensation on the interior surface of the specimen, it is unlikely that the relative humidity of the air during the test (building interior ambient conditions) was identical in the two test laboratories. Nonetheless, because maximum relative humidity for avoiding condensation is approximately 15%, we do not believe this variable influences test results.

6.5 CONCLUSIONS

- The results obtained by the two test laboratories demonstrate method reproducibility for the three specimens selected.

- Result reproducibility may be affected by irreversible and/or reversible differential movement of window system components.

- The primary factor underlying result variation is linked to the test procedure used by each laboratory.

7. ANALYSIS OF RESULTS AND DISCUSSION

7.1 SELECTION OF TEST TEMPERATURE

7.1.1 WINTER CONDITIONS

Selection of the air temperature representing ambient conditions outside the building should be made on the basis of the following factors:

- maintain comfortable interior ambient conditions throughout the winter;
- accurately evaluate energy losses related to air leakage at low temperatures, with a view to installing an appropriate heating system;
- minimize energy consumption during the winter months.

Unlike the energy consumption factor, which depends on average outside temperature, the first two factors are closely related to the minimum temperature recorded during the month of January for the target location (2.5% Jan. temp.).

Conclusion

To deal with the three factors listed above, the test temperature selected should be the 2.5% January temperature specified in the NBCC Supplement.

Recommendation

To reduce the cost of testing and comply with the conditions set out in the resistance to condensation test defined in the CAN/CSA-A440-M90 standard, we propose:

that all windows equipped with one or more sashes (fixed or movable) comply with the existing product classification according to the

CAN/CSA-A440-M90 standard (i.e. A1, A2, A3, fixed) when tested according to the ASTM E-1424-91 standard at an external ambient air temperature of -30°C and an interior building temperature of 20°C.

The A440 standard should also include a comment to the effect that, where the minimum January temperature (2.5% Jan. temp.) is below -30°C for a given location, the specifications should include the test temperature.

7.1.2 SUMMER CONDITIONS

The test results obtained according to the ASTM E1424-91 standard demonstrate that the air infiltration rate at high temperature (T = 50°C on weather-side) is virtually equal to the air infiltration rate at 20°C.

The test method specified in the ASTM E1424-91 standard is not representative of real summer conditions. In fact, this test method contemplates maintaining outside air temperature at 50°C; while under the actual operating conditions, the surface temperature of the extrusions exposed to exterior ambient conditions can range between 50°C (light colour) and 70°C (dark colour).

Thus the air infiltration rate measured using this method is less than the rate that would be observed under actual operating conditions.

Conclusions

- The high temperature test method defined in the ASTM E1424-91 standard is not representative of summer window operating conditions.

- The air infiltration rate measured by this method is less than the rate measured under actual operating conditions.

Recommendation

If the person writing window performance specifications wishes to ensure a good airtightness during exposure to high outdoor temperatures, the method should specify a radiant heat source for maintaining the average exterior surface temperature of the extrusions at a given value (e.g. 50°C) at an outdoor air temperature of 30°C and an indoor air temperature of 20°C.

The ASTM E06051 subcommittee is currently developing this test method. The standard is to be entitled "Standard Practice to Determine the Effects of Temperature Cycling Plus Infrared Radiation on Window and Door Systems".

7.2 SELECTION OF TEST PRESSURE DIFFERENTIAL (WINTER)

In small buildings (number of stories ≤ 3), the average pressure differential (winter) acting on the building envelope is between 5 and 10 Pa approximately, whereas the peak pressure differential for determining heating system requirements is 30 to 50 Pa.

In high-rise buildings equipped with a fresh air intake system, pressure differential is closely linked to building height (stack effect) and mechanical system control. However, the difference in pressure recorded at ground level and on the top floor is rarely more than 75 Pa: above this pressure difference, the effort required by occupants to open and close building access doors is unacceptable.

Conclusion

The test pressure differential (75 Pa) used in the CAN/CSA-A440-M90 standard is valid for all buildings.

7.3 VARIATION IN AIR INFILTRATION RATE AS A FUNCTION OF EXTERIOR AMBIENT TEMPERATURE (ΔP = CONSTANT)

Table 6 shows, for a given pressure differential (75 Pa or 300 Pa), the relationship between air infiltration rate measured at outdoor ambient temperatures of -30°C, 0°C and 50°C and air infiltration rate measured at 20°C.

The following points emerge.

(a) Low external exposure temperature (T < 20°C)

- With the exception of one window (specimen 21), all windows demonstrate an increase in air infiltration rate with a drop in external exposure temperature.

- For all specimens demonstrating an increase in infiltration rate at low temperature, the ratio I -30°C/I 20°C varies between 1.11 and 5.0 (ΔP = 75 Pa).

- The significance of the air infiltration rate variation appears to depend on window type. Some casement windows appear more subject to a large increase in air infiltration rate at low temperature.

- The variation in air infiltration rate for a given product cannot be linked to the type of frame and sash material (PVC, aluminum, wood); it is rather a factor of overall product design. The tests conducted on specimens 8, 9 and 10 demonstrate that, by changing the hardware and/or the diameter of the bulb weatherstrip, the behaviour of a window can be radically changed. For this casement window, the ratio I -30°C/I 20°C dropped from 5 to 1.23.

- Specimen 21 was unique. At ambient room temperature (T ≈ 20°C), the primary sash/frame weatherstrip demonstrates little or no compression, producing a high air infiltration rate. Conversely, at low temperature, the warping of sash members increases primary weatherstrip compression and improves the product airtightness.

(b) <u>High external exposure temperature T > 20°C</u>

- For most specimens, the influence of an increase in exterior temperature (according to the ASTM E1424-91 standard method) is less than the influence of an equivalent temperature decrease.

- For all specimens, the ratio I 50°C/I 20°C varies between 0.65 and 1.89 (ΔP = 75 Pa).

TABLE 6: VARIATION IN RATE OF AIR INFILTRATION AS A FUNCTION OF EXTERNAL AMBIENT TEMPERATURE

REFERENCE: I_{BASE} EVALUATED AT 20°C

SPECIMEN NO.	WINDOW TYPE	ΔP = 75 Pa			ΔP = 300 Pa		
		I -30°C / I 20°C	I 0°C / I 20°C	I 50°C / I 20°C	I -30°C / I 20°C	I 0°C / I 20°C	I 50°C / I 20°C
1	Casement	2.44	1.44	0.84	2.12	1.53	0.93
2	Casement	1.25	1.25	1.35	1.27	1.21	1.25
3	Casement	2.5	1.16	1.89	2.35	1.59	1.69
4	Casement	3.0	1.16	1.83	-	-	-
5	Casement	2.0	2.0	1.83	1.73	1.46	1.07
6	Casement	1.44	1.31	1.0	1.29	1.20	1.09
7	Casement	4.81	1.52	0.91	3.57	1.24	0.91
8	Casement	5.0	1.03	1.22	3.70	0.98	0.98
9	Casement	3.46	1.12	1.37	2.63	1.03	1.03
10	Casement	1.23	1.11	1.17	1.34	1.13	1.13
11	Casement	3.31	1.30	1.05	4.05	1.81	1.06
12	Casement	1.32	1.09	1.12	1.41	1.14	1.04
13	Casement	3.12	1.56	1.04	2.06	1.20	0.90
14	Casement	1.88	1.24	1.03	1.83	1.34	1.08
15	Tilt-turn	1.57	1.08	1.13	1.42	1.03	1.05
16	Awning	1.16	1.11	1.11	1.24	1.12	1.07
17	Hor. slider	1.11	1.14	1.02	1.18	1.05	0.95
18	Hor. slider	1.71	1.37	0.65	1.09	0.95	0.83
19	Hor. slider	1.16	1.05	0.92	1.14	1.03	0.89
20	Vert. slider	1.35	1.26	1.04	1.46	1.22	0.98
21	Vert. slider	0.57	0.68	1.01	0.76	0.93	1.12
22	Vert. slider	2.49	1.58	1.77	*	*	*

* Exceeds maximum limit of air flow measurement.

7.4 PRODUCT CLASSIFICATION

The current classification of windows according to the CAN/CSA-A440-M90 standard was established for interior and exterior ambient conditions of 20°C.

Table 7 shows the classification of the specimens tested for all exterior ambient temperatures (T = -30°C, 0°C, 20°C, 50°C), considering that the maximum air infiltration rate for a given category (A1, A2, A3) remains constant.

TABLE 7: SPECIMEN CLASSIFICATION AS A FUNCTION OF TEST TEMPERATURE (ΔP = 75 Pa)

SPECIMEN NO.	WINDOW TYPE	CLASSIFICATION*			
		-30°C	0°C	20°C (A440)	50°C
1	Casement	A2	A2	A3	A3
2	Casement	A3	A3	A3	A3
3	Casement	A3	A3	A3	A3
4	Casement	A3	A3	A3	A3
5	Casement	A3	A3	A3	A3
6	Casement	A3	A3	A3	A3
7	Casement	NC**	A2	A2	A3
8	Casement	A2	A3	A3	A3
9	Casement	A2	A3	A3	A3
10	Casement	A2	A3	A3	A3
11	Casement	A1	A2	A2	A2
12	Casement	A3	A3	A3	A3
13	Casement	A2	A3	A3	A3
14	Casement	A2	A2	A2	A2
15	Tilt-turn	A2	A3	A3	A3
16	Awning	A3	A3	A3	A3
17	Hor. slider	A2	A2	A3	A2
18	Hor. slider	NC**	A1	A1	A2
19	Hor. slider	A2	A2	A2	A2
20	Vert. slider	A2	A2	A3	A3
21	Vert. slider	A2	A3	NC**	NC**
22	Vert. slider	NC**	NC**	NC**	NC**

* Classification of windows according to CAN/CSA-A440-M90

A3: $I \leq 0.55$ m3/h-m @ ΔP = 75 Pa

A2: $0.55 < I \leq 1.65$ m3/h-m @ ΔP = 75 Pa

A1: $1.65 < I \leq 2.79$ m3/h-m @ ΔP = 75 Pa

** NC: Does not comply (standard A440): $I > 2.79$ m3/h-m @ ΔP = 75 Pa

The Table 7 data demonstrate the following points:

(a) If, during testing, the outside air temperature is -30°C, a number of windows should be reclassified. Of the 20 products classified according to the current standard:

- nine products would remain in the category determined at 20°C;
- eight products would move from category A3 to A2;
- one product would move from category A2 to A1;
- two products would no longer be classified;

(b) If, during testing, the outside air temperature is 0°C, three windows (of the 20 products classified according to the existing standard) should be reclassified:

- the three products would move from category A3 to A2.

7.5 INFLUENCE OF TEST PRESSURE DIFFERENTIAL

Table 3 results show that, for a given test temperature, air infiltration rate increases with an increase in pressure differential. However, it is impossible to develop a relationship between air infiltration rate and pressure differential for all windows or a given window type. The influence of pressure differential on air infiltration rate is closely linked to individual overall product design (e.g. frame rigidity, number and position of locks, airtightness system definition).

8. CONCLUSIONS

8.1 TEST METHOD

With the exception of a few small changes, the test method defined by the ASTM E1424-91 standard is excellent for measuring air leakage at low temperatures (absence of solar radiation). Nonetheless, for measuring leakage at high temperature, the ASTM E1424-91 standard gives unrealistic values since the exposure conditions are not representative.

The changes to the reference standard required for measuring air flow across windows are aimed primarily at evaluating extraneous air leakage from the test chamber. The following points should be modified.

(a) To adequately measure extraneous air leakage across the test chamber, the polyethylene film should be firmly anchored to the mask wall rather than the window frame.

(b) When measuring extraneous air leakage across the test chamber, the pressure difference between the weather-side chamber and the cavity formed by the polyethylene film and the window should be equal to the pressure difference for which extraneous leakage is being measured. Perfection being unattainable, the testing agency should keep the pressure differential across the film equal to the pressure differential for which leakage is measured plus or minus 3%.

8.2 RATE OF AIR INFILTRATION THROUGH WINDOWS AS A FUNCTION OF A TEMPERATURE GRADIENT AND A PRESSURE GRADIENT

(A) CONCLUSIONS

- Irrespective of window type, frame and operable sash materials and overall design (e.g. number of locking points, snubbers, weatherstrip dimensions and shape), all the windows submitted for testing experienced a variation in air infiltration rates as a function of outdoor air temperature in relation to reference temperature, i.e. T = 20°C.

- For a given window type (casement, awning, slider), the change in air leakage rate as a function of outdoor air temperature is closely tied to overall product design.

- With the exception of one window (specimen 21), all tests revealed that for a given pressure differential (e.g. 75 Pa), the air infiltration rate rises with a drop in outdoor air temperature ($T_{EXT} < 20°C$).
  - At an outdoor air temperature of 0°C, air leakage is 1.03 to 2.0 times the value measured at 20°C.
  - At an outdoor air temperature of -30°C, air leakage is 1.11 to 5.0 times the value measured at 20°C.

- For a given pressure differential (75 Pa) and an outdoor air temperature of 50°C, the rate of air leakage measured across most specimens shows a slight increase or decrease when compared to the value measured at 20°C. The air leakage ratio at I 50°C/I 20°C varies between 0.65 and 1.89.

9. RECOMMENDATIONS

To ensure occupant comfort, low energy consumption and accurate assessment of heating system requirement, we make the following recommendations.

(a) When tested in accordance with the ASTM E1424-91 standard at an outdoor air temperature of -30°C and an indoor building air temperature of 20°C, all windows consisting of one or more sashes (fixed or movable) should meet the existing classification requirements of the CAN/CSA-A440-M90 standard (i.e. A1, A2, A3, fixed).

(b) Incorporate into the ASTM E1424-91 test procedure the modifications specified with respect to attachment of the polyethylene film and measurement of the pressure differential across this film.

REFERENCE WORKS

1. D.W. Kehrli, "Window and Door Air Leakage Tests Predict Real World Performance", Fenestration, Nov.-Dec. 1989, p. 18 to 21.

2. D.W. Kehrli, "Window Air Leakage Performance as a Function of Differential Temperatures and Accelerated Environmental Aging", ASHRAE Transaction 1990.

3. ASTM E1424, "Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure and Temperature Differences Across the Specimen", 1991.

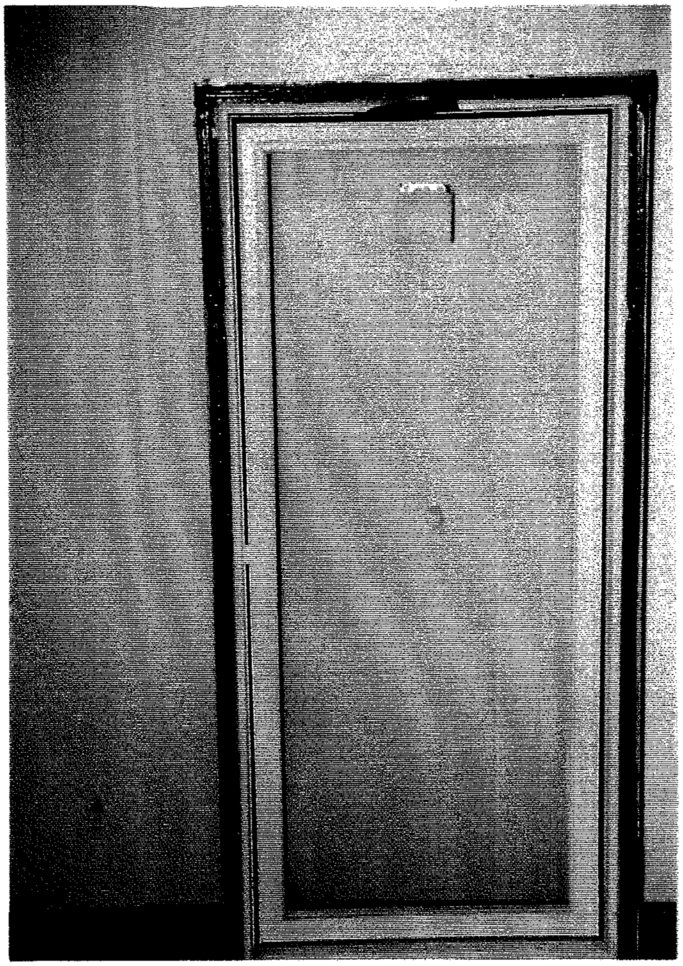
4. A.H. Elmahdy, "Air Leakage Characteristics of Windows Subjected to Simultaneous Temperature and Pressure Differentials", Window Innovations '95 Proceedings, Toronto, June 95, pp. 146-163.

5. ASTM, subcommittee E06051, "Standard Practice to Determine the Effects of Temperature Cycling Plus Infrared Radiation on Window and Door Systems", Draft 16, March 29, 1994.

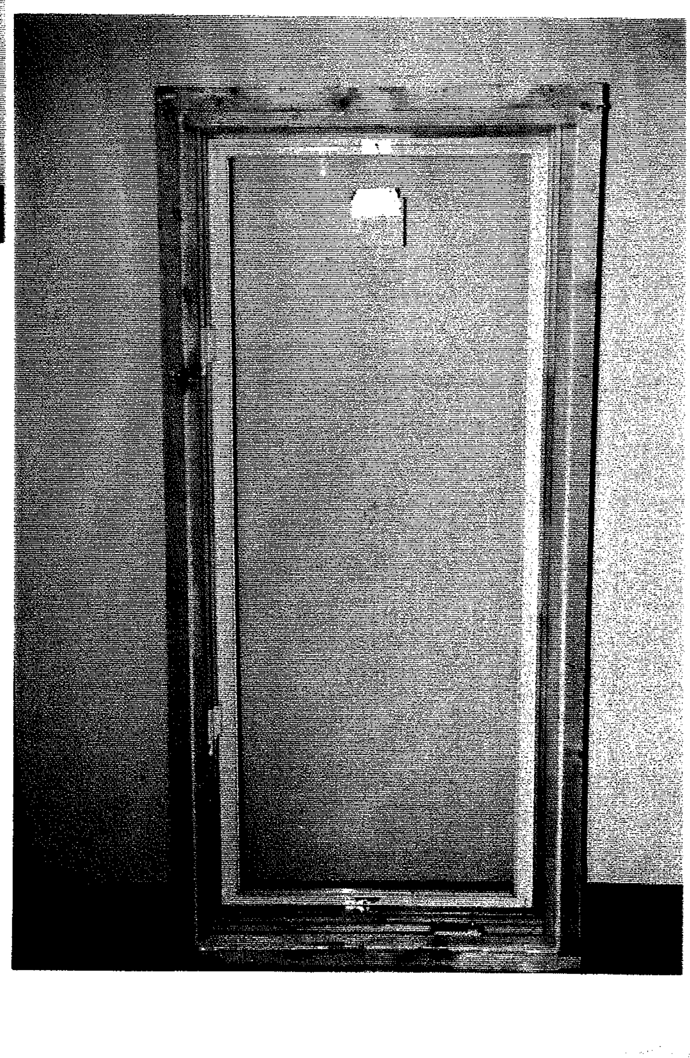
APPENDIX "A"

DESCRIPTION OF SPECIMENS
(Photographs, technical descriptions)

SPECIMEN 1



Outside Elevation



Inside Elevation

SPECIMEN 1

TECHNICAL DESCRIPTION

WINDOW TYPE: Crank-operated casement
FRAME MATERIAL: Wood, PVC cladding
OPERABLE SASH MATERIAL: Extruded PVC
EXT. FRAME DIMENSIONS: 700 mm wide x 1580 mm high
EXT. SASH DIMENSIONS: 646 mm wide x 1527 mm high
CRACK LENGTH: 4.39 m
SNUBBER (AXIS OF ROTATION SIDE): 1 exterior snubber at centre of stile

SASH REINFORCEMENT: Wood reinforced stiles and rails

GLAZING:

TYPE:	CHARACTERISTICS:
_X_ DOUBLE (FACTORY SEALED)	- THICKNESS OF GLASS: 3 mm
_____ DOUBLE (SEPARATE SASH)	- SPACER TYPE: Aluminum
	- TOTAL THICKNESS: 18 mm

DESCRIPTION OF SEALING SYSTEM:

Single weatherstripping system. Outside double blade sweep-style seal attached to sash.

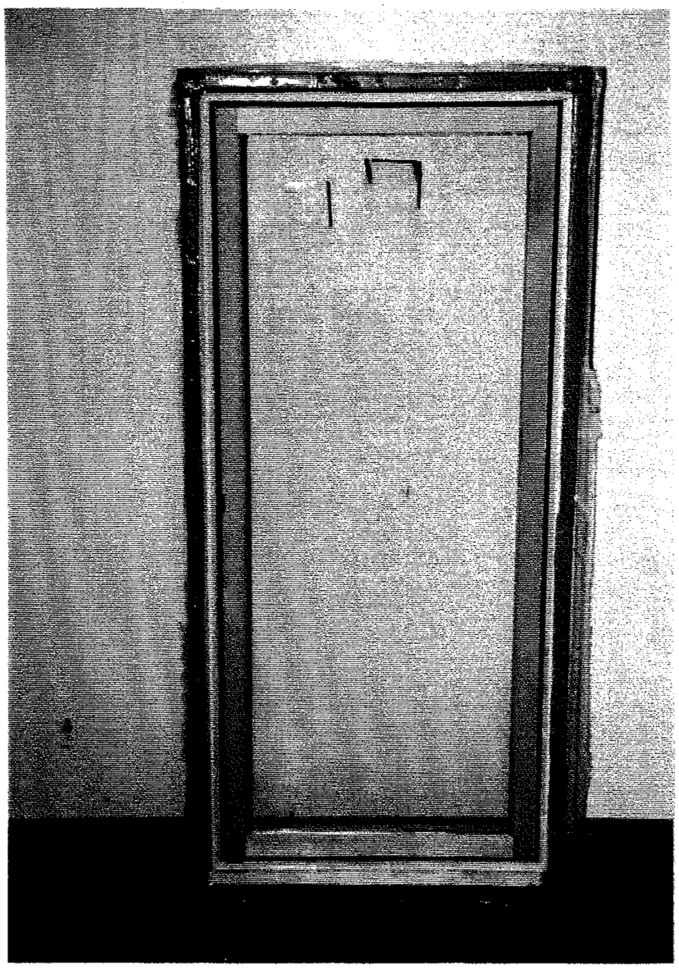
DESCRIPTION OF LOCKING SYSTEM:

Two cam latches. The locking points are set vertically at 430 mm and 1160 mm from bottom of sash.

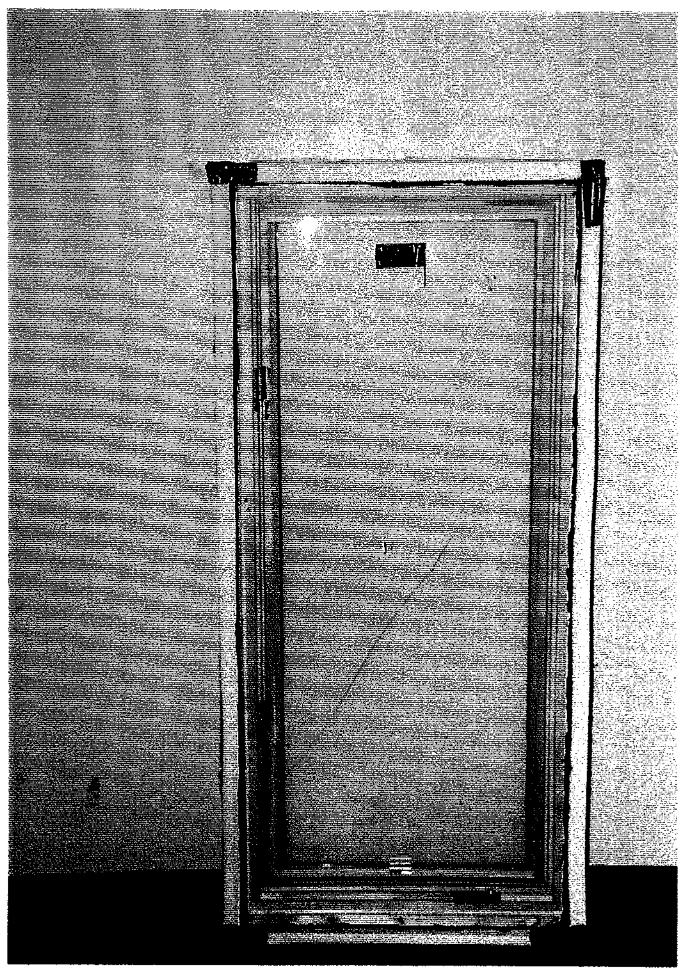
FRAME TO SUBFRAME ANCHORING:

Each jamb of the frame is screwed to the wooden subframe using six #8 - 2 1/2" screws. Two screws near head, two near sill and one each at 1/3 and 2/3 of height.

SPECIMEN 2



Outside Elevation



Inside Elevation

SPECIMEN 2

TECHNICAL DESCRIPTION

WINDOW TYPE: Crank-operated casement
FRAME MATERIAL: Wood
OPERABLE SASH MATERIAL: Wood
EXT. FRAME DIMENSIONS: 700 mm wide x 1580 mm high
EXT. SASH DIMENSIONS: 651 mm wide x 1531 mm high
CRACK LENGTH: 4.38 m
SNUBBER (AXIS OF ROTATION SIDE): 1 outside snubber at midpoint of stile

SASH REINFORCEMENT: None

GLAZING:

TYPE:		CHARACTERISTICS:
X DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: 3 mm
_____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: Aluminum
	-	TOTAL THICKNESS: 18 mm

DESCRIPTION OF SEALING SYSTEM:

Single weatherstripping system. Outside double blade sweep-style seal attached to sash.

DESCRIPTION OF LOCKING SYSTEM:

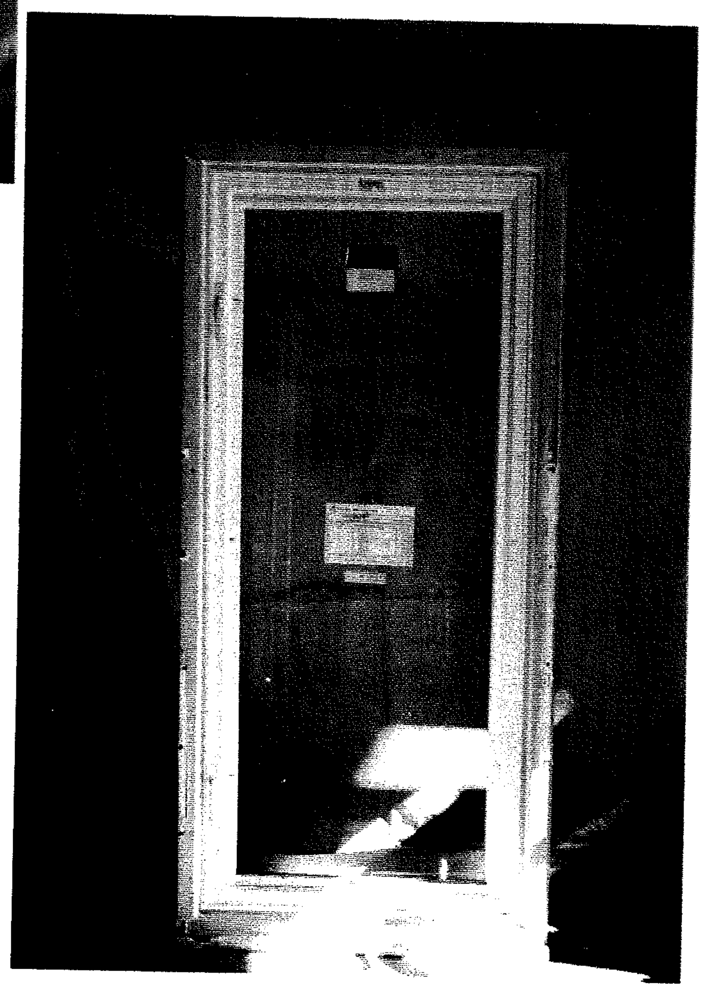
Two cam latches. The locking points are set vertically at 425 mm and 1154 mm from bottom of sash.

FRAME TO SUBFRAME ANCHORING:

Each stile in the frame is screwed to the wooden subframe using six #8 - 2 1/2" screws. Two screws near head, two near the sill and one each at 1/3 and 2/3 of height.

SPECIMEN 3

Outside Elevation



Inside Elevation

SPECIMEN 3

TECHNICAL DESCRIPTION

WINDOW TYPE: Crank-operated casement
FRAME MATERIAL: Wood and PVC
OPERABLE SASH MATERIAL: Extruded PVC
EXT. FRAME DIMENSIONS: 702 mm wide x 1583 mm high
EXT. SASH DIMENSIONS: 647 mm wide x 1528 mm high
CRACK LENGTH: 4.17 m
SNUBBER (AXIS OF ROTATION SIDE): 1 exterior snubber at centre of stile

SASH REINFORCEMENT: Wood reinforced stiles and rails

GLAZING:

TYPE:		CHARACTERISTICS:
_X_ DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: 3 mm
_____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: Aluminum
	-	TOTAL THICKNESS: 19 mm

DESCRIPTION OF SEALING SYSTEM:

Double weatherstripping system. Outside sweep-style seal provided by a pile strip attached to sash. Inside compression seal provided by a bulb attached to frame.

DESCRIPTION OF LOCKING SYSTEM:

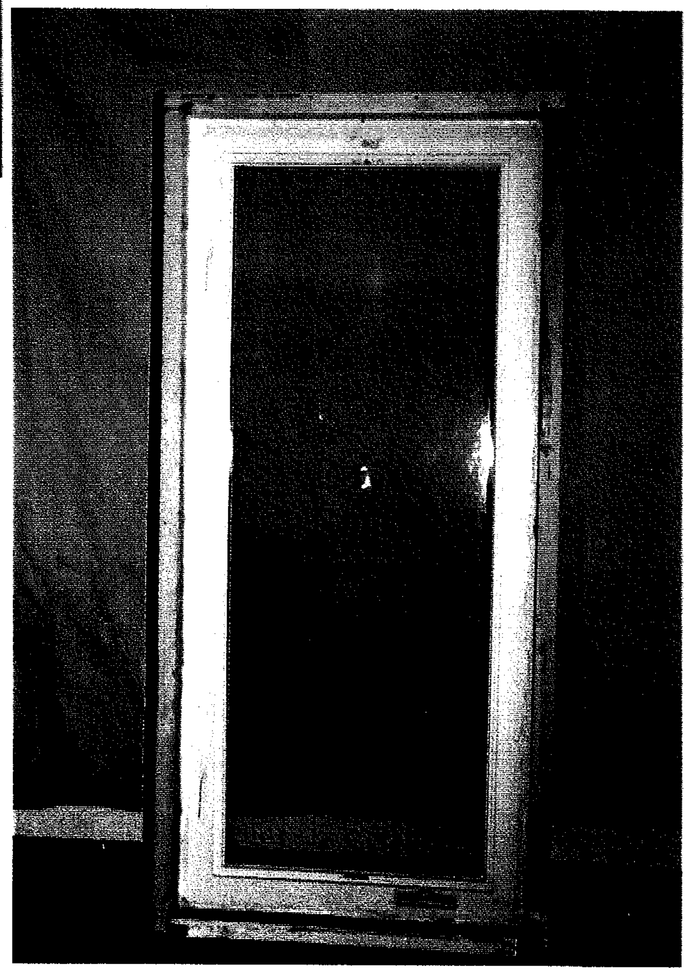
Two cam latches. Locking points located vertically at 275 mm and 1285 mm from bottom of sash.

FRAME TO SUBFRAME ANCHORING:

Each stile of the frame is screwed to the wooden subframe by eight #8 - 2 1/2" screws.

SPECIMEN 4

Outside Elevation



Inside Elevation

SPECIMEN 4

TECHNICAL DESCRIPTION

WINDOW TYPE: Crank-operated casement
FRAME MATERIAL: Extruded PVC
OPERABLE SASH MATERIAL: Extruded PVC
EXT. FRAME DIMENSIONS: 593 mm wide x 1593 mm high
EXT. SASH DIMENSIONS: 657 mm wide x 1556 mm high
CRACK LENGTH: 4.29 m
SNUBBER (AXIS OF ROTATION SIDE): 1 pair of snubbers located at the centre of the stile.

SASH REINFORCEMENT: None

GLAZING:

TYPE:		CHARACTERISTICS:
_X_ DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: 3 mm
_____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: Aluminum
	-	TOTAL THICKNESS: 22 mm

DESCRIPTION OF SEALING SYSTEM:

Triple weatherstripping system. Outside sweep-type seal provided by pile strip attached to sash. Intermediate compression seal provided by bulb attached to frame. Inside compression seal provided by bulb attached to frame.

DESCRIPTION OF LOCKING SYSTEM:

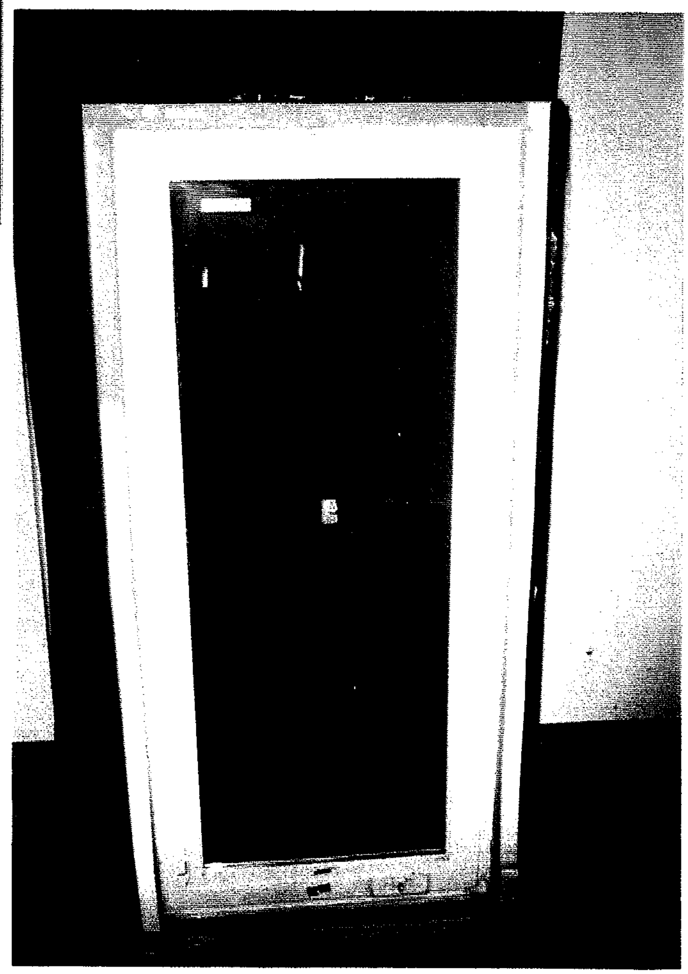
Two cam latches. The locking points are set vertically at 255 mm and 1320 mm from bottom of sash.

FRAME TO SUBFRAME ANCHORING:

Floating installation with eight metal fasteners (three fasteners per jamb, two fasteners per sill).

SPECIMEN 5

Outside Elevation



Inside Elevation

SPECIMEN 5

TECHNICAL DESCRIPTION

WINDOW TYPE: Crank-operated casement
FRAME MATERIAL: Extruded PVC
OPERABLE SASH MATERIAL: Extruded PVC
EXT. FRAME DIMENSIONS: 700 mm wide x 1600 mm high
EXT. SASH DIMENSIONS: 656 mm wide x 1556 mm high
CRACK LENGTH: 4.35 m
SNUBBER (AXIS OF ROTATION SIDE): 1 pair of snubbers at midpoint of stile.

SASH REINFORCEMENT: Metal reinforced stiles.

GLAZING:

TYPE:		CHARACTERISTICS:
_X_ DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: 3 mm
____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: Aluminum
	-	TOTAL THICKNESS: 22 mm

DESCRIPTION OF SEALING SYSTEM:

Triple weatherstripping system. Outside sweep-style seal provided by pile strip slotted into sash. Intermediate compression seal provided by bulb slotted into frame. Inside pressure seal provided by a flexible strip coextruded on the frame.

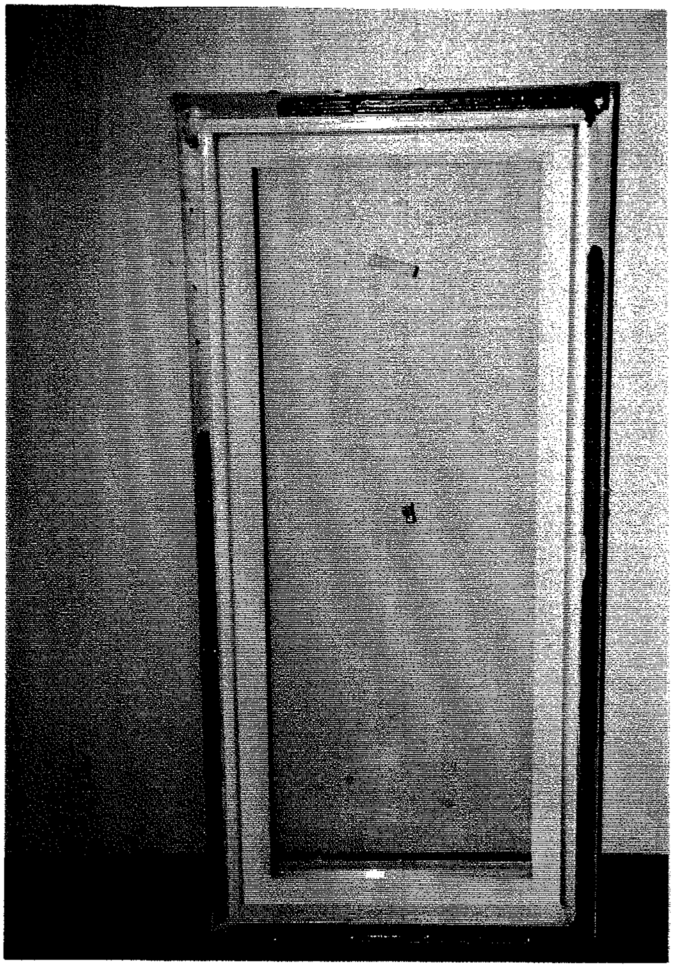
DESCRIPTION OF LOCKING SYSTEM:

Single lever multipoint (three locking points) system. The locks are positioned vertically at 245 mm, 845 and 1420 mm from bottom of sash.

FRAME TO SUBFRAME ANCHORING:

Floating installation with eight metal fasteners (three fasteners per jamb, two fasteners per sill).

SPECIMEN 6



Outside Elevation

Inside Elevation

SPECIMEN 6

TECHNICAL DESCRIPTION

WINDOW TYPE: Crank-operated casement
FRAME MATERIAL: Extruded PVC
OPERABLE SASH MATERIAL: Extruded PVC
EXT. FRAME DIMENSIONS: 700 mm wide x 1598 mm high
EXT. SASH DIMENSIONS: 651 mm wide x 1555 mm high
CRACK LENGTH: 4.33 m
SNUBBER (AXIS OF ROTATION SIDE): 2 pairs located at 1/3 and 2/3 of stile height.

SASH REINFORCEMENT: None

GLAZING:

TYPE:		CHARACTERISTICS:
_X_ DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: 3 mm
_____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: Aluminum
	-	TOTAL THICKNESS: 22 mm

DESCRIPTION OF SEALING SYSTEM:

Double weatherstripping system. Outside sweep-style seal provided by pile strip attached to sash. Inside compression seal provided by a plastic-film-wrapped foam bulb attached to frame.

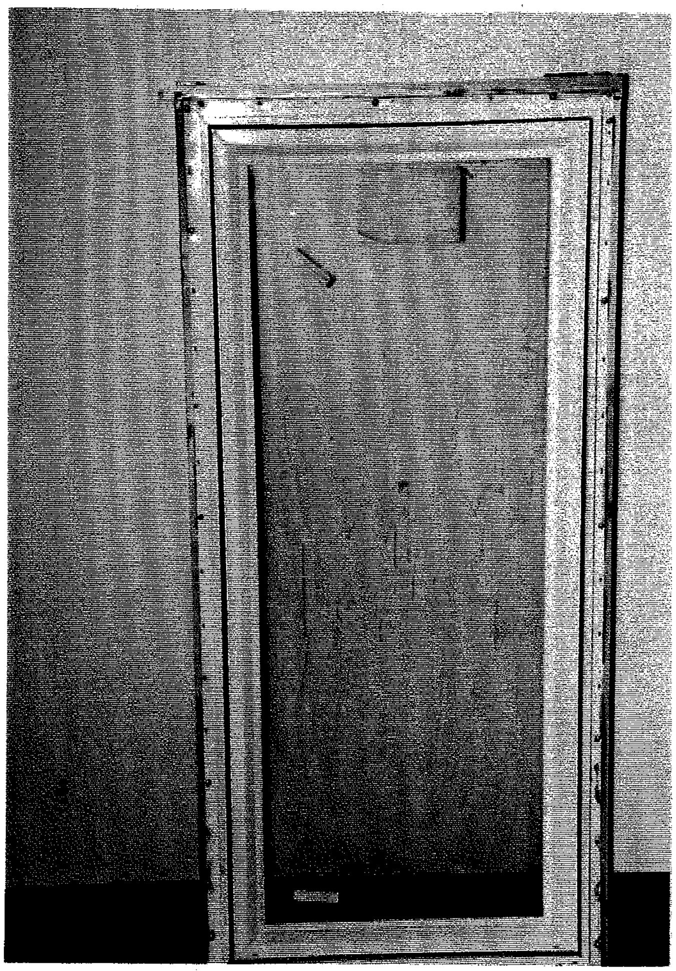
DESCRIPTION OF LOCKING SYSTEM:

Three cam latches. The locking points are located vertically at 240 mm, 780 mm and 1320 mm from bottom of sash.

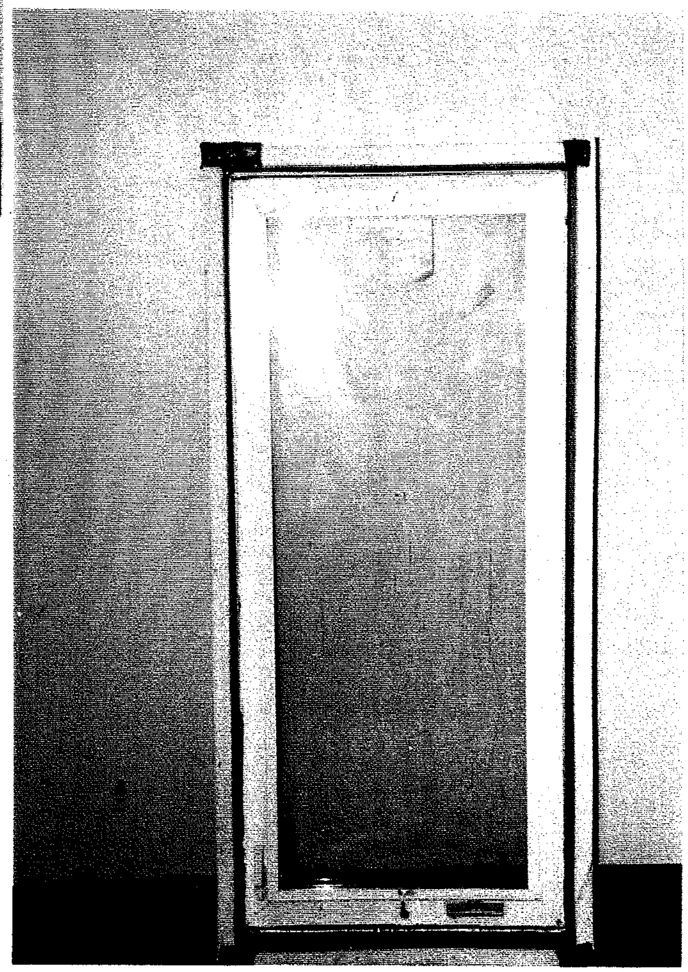
FRAME TO SUBFRAME ANCHORING:

Floating installation with eight metal fasteners (three fasteners per jamb, two fasteners per sill).

SPECIMEN 7



Outside Elevation



Inside Elevation

SPECIMEN 7

TECHNICAL DESCRIPTION

WINDOW TYPE: Crank-operated casement
FRAME MATERIAL: Extruded PVC
OPERABLE SASH MATERIAL: Extruded PVC
EXT. FRAME DIMENSIONS: 703 mm wide x 1599 mm high
EXT. SASH DIMENSIONS: 664 mm wide x 1559 mm high
CRACK LENGTH: 4.36 m
SNUBBER (AXIS OF ROTATION SIDE): 2 pairs of snubbers located at 1/3 and 2/3 of the stile.

SASH REINFORCEMENT: None

GLAZING:

TYPE:		CHARACTERISTICS:
_X_ DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: 3 mm
_____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: Aluminum
	-	TOTAL THICKNESS: 24 mm

DESCRIPTION OF SEALING SYSTEM:

Double weatherstripping system. Outside sweep-style seal provided by flexible V-strip slotted into sash. Inside compression seal provided by flexible V-strip slotted into frame.

DESCRIPTION OF LOCKING SYSTEM:

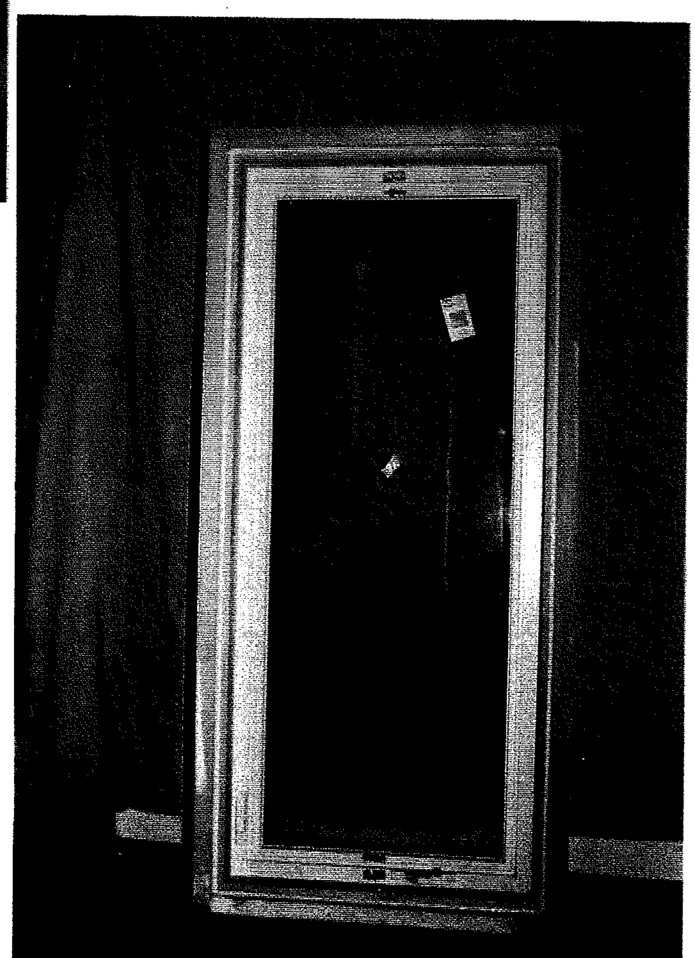
Single lever multipoint (three locking points) system. The locking points are located vertically at 216 mm, 826 mm and 1397 mm from bottom of sash.

FRAME TO SUBFRAME ANCHORING:

The mounting flange extruded from the window frame is screwed to the face of the wood subframe using five #8 - 1 1/2" screws per jamb and three #8 - 1 1/2" screws at head and sill.

SPECIMENS 8-9

Outside Elevation



Inside Elevation

SPECIMENS 8-9

TECHNICAL DESCRIPTION

WINDOW TYPE: Crank-operated casement
FRAME MATERIAL: Extruded PVC and wood
OPERABLE SASH MATERIAL: Extruded PVC
EXT. FRAME DIMENSIONS: 700 mm wide x 1598 mm high
EXT. SASH DIMENSIONS: 656 mm wide x 1554 mm high
CRACK LENGTH: 4.32 m
SNUBBER (AXIS OF ROTATION SIDE): 2 pairs of snubbers located at 1/3 and 2/3 of stile.

SASH REINFORCEMENT: None

GLAZING:

TYPE:		CHARACTERISTICS:
_X_ DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: 3 mm
_____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: PVC
	-	TOTAL THICKNESS: 22 mm

DESCRIPTION OF SEALING SYSTEM:

Triple weatherstripping system. Specimen 8 - small diameter bulb; specimen 9 - larger diameter bulb. Outside sweep-style seal provided by pile strip attached to sash. Intermediate compression seal provided by bulb attached to sash. Inside compression seal provided by bulb attached to frame.

DESCRIPTION OF LOCKING SYSTEM:

Single lever multipoint (three locking points) system. The locking points are located vertically at 245 mm, 645 mm and 1420 mm from bottom of sash.

FRAME TO SUBFRAME ANCHORING:

The wooden projection located on inside of frame is screwed to subframe by three #8 - 2 1/2" screws per jamb.

SPECIMEN 10

Outside Elevation

Inside Elevation

SPECIMEN 10

Same window model as specimens 8 and 9

TECHNICAL DESCRIPTION

WINDOW TYPE: Crank-operated casement
FRAME MATERIAL: Extruded PVC and wood
OPERABLE SASH MATERIAL: Extruded PVC
EXT. FRAME DIMENSIONS: 700 mm wide x 1600 mm high
EXT. SASH DIMENSIONS: 656 mm wide x 1556 mm high
CRACK LENGTH: 4.32 m
SNUBBER (AXIS OF ROTATION SIDE): 2 pairs of snubbers located at 1/3 and 2/3 of stile.

SASH REINFORCEMENT: None

GLAZING:

<u>TYPE</u>:
__X__ DOUBLE (FACTORY SEALED)
_____ DOUBLE (SEPARATE SASH)

<u>CHARACTERISTICS</u>:
- THICKNESS OF GLASS: 3 mm
- SPACER TYPE: PVC
- TOTAL THICKNESS: 22 mm

DESCRIPTION OF SEALING SYSTEM:

Triple weatherstripping system. Identical to specimen 9.

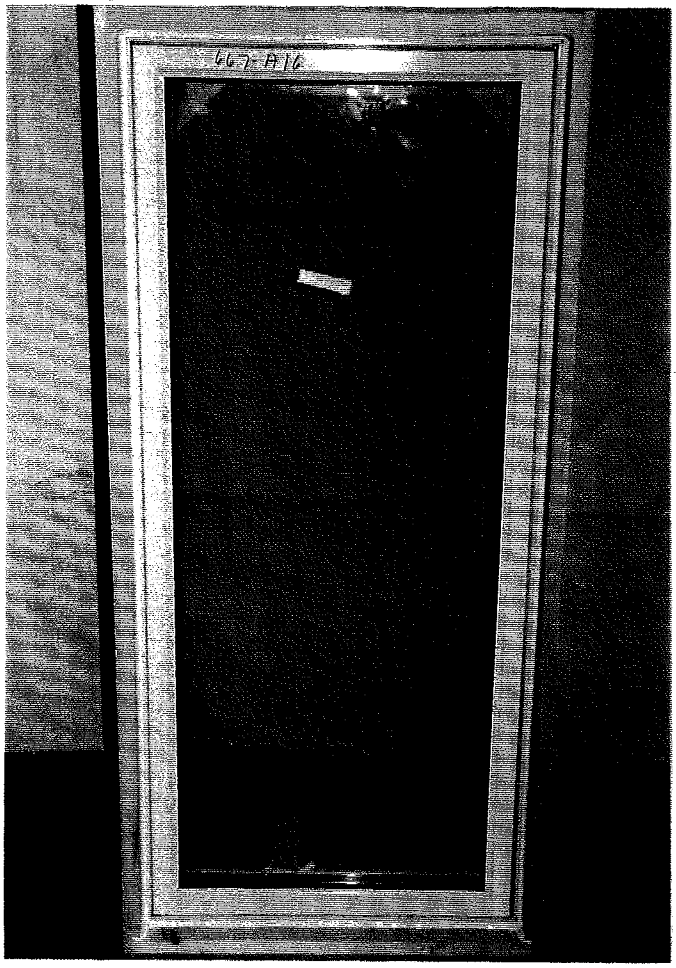
DESCRIPTION OF LOCKING SYSTEM:

Two cam latches. Locking points are located vertically at 200 mm and 1385 mm from bottom of sash.

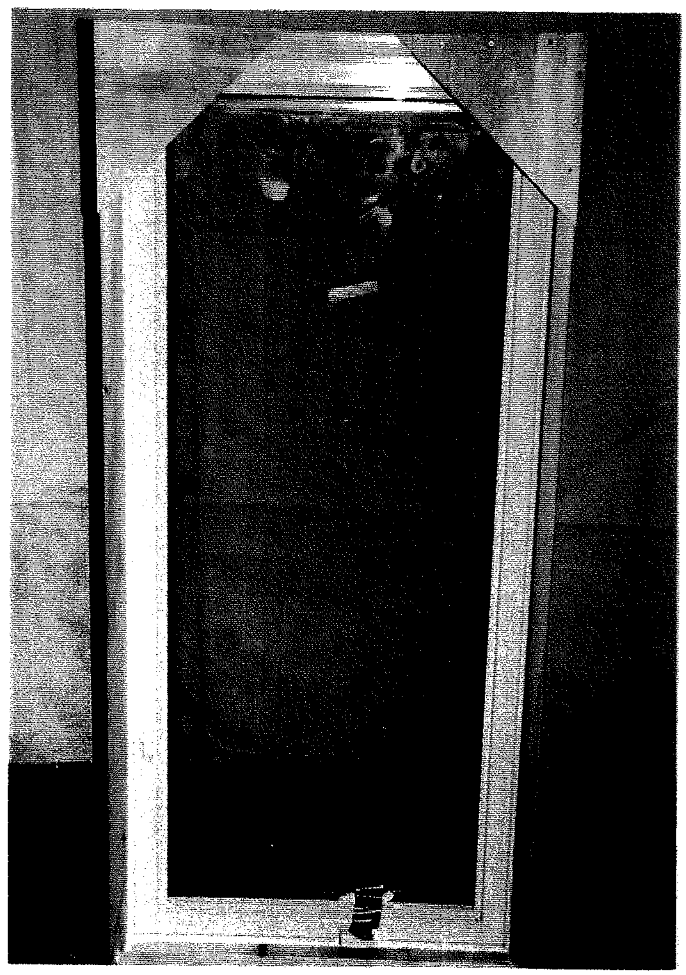
FRAME TO SUBFRAME ANCHORING:

The wooden projection located on inside of frame is screwed to subframe by three #8 - 2 1/2" screws per jamb.

SPECIMEN 11



Outside Elevation



Inside Elevation

SPECIMEN 11

TECHNICAL DESCRIPTION

WINDOW TYPE: Crank-operated casement
FRAME MATERIAL: Extruded aluminum with thermal break
OPERABLE SASH MATERIAL: Extruded aluminum with thermal break
EXT. FRAME DIMENSIONS: 705 mm wide x 1607 mm high
EXT. SASH DIMENSIONS: 676 mm wide x 1580 mm high
CRACK LENGTH: 4.418 m
SNUBBER (AXIS OF ROTATION SIDE): None

SASH REINFORCEMENT: None

GLAZING:

TYPE:		CHARACTERISTICS:
_X_ DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: 3 mm
_____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: Aluminum
	-	TOTAL THICKNESS: 32 mm

DESCRIPTION OF SEALING SYSTEM:

Triple weatherstripping system. Outside sweep-style seal provided by pile strip attached to sash. Intermediate compression seal provided by rubber strip attached to frame. Inside compression seal provided by bulb attached to frame.

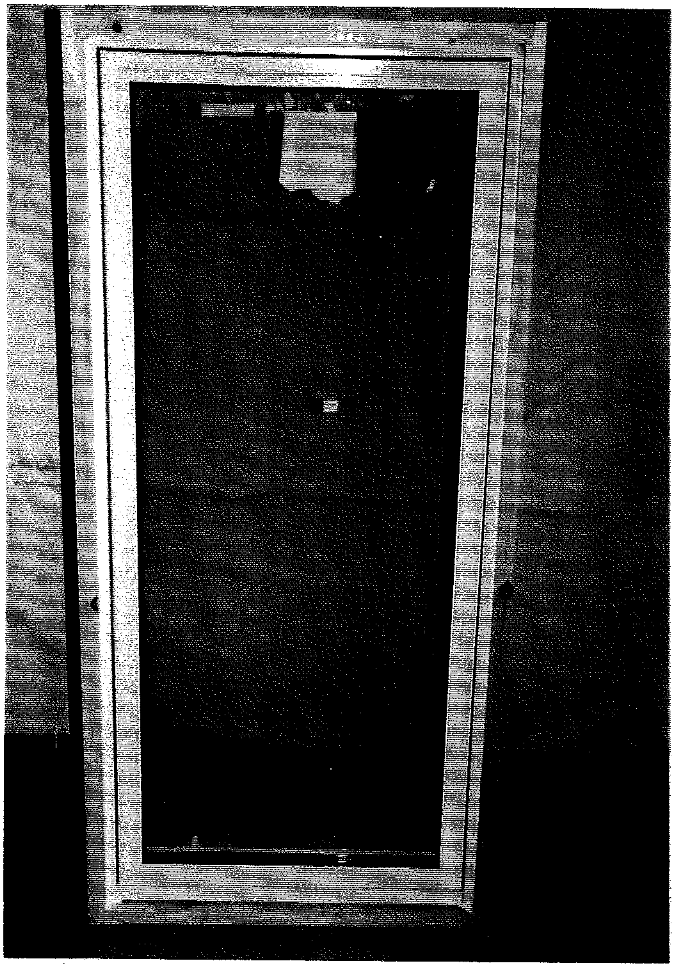
DESCRIPTION OF LOCKING SYSTEM:

Single lever multipoint (two locking points) system. The locks are positioned vertically at 275 mm and 1320 mm from bottom of sash.

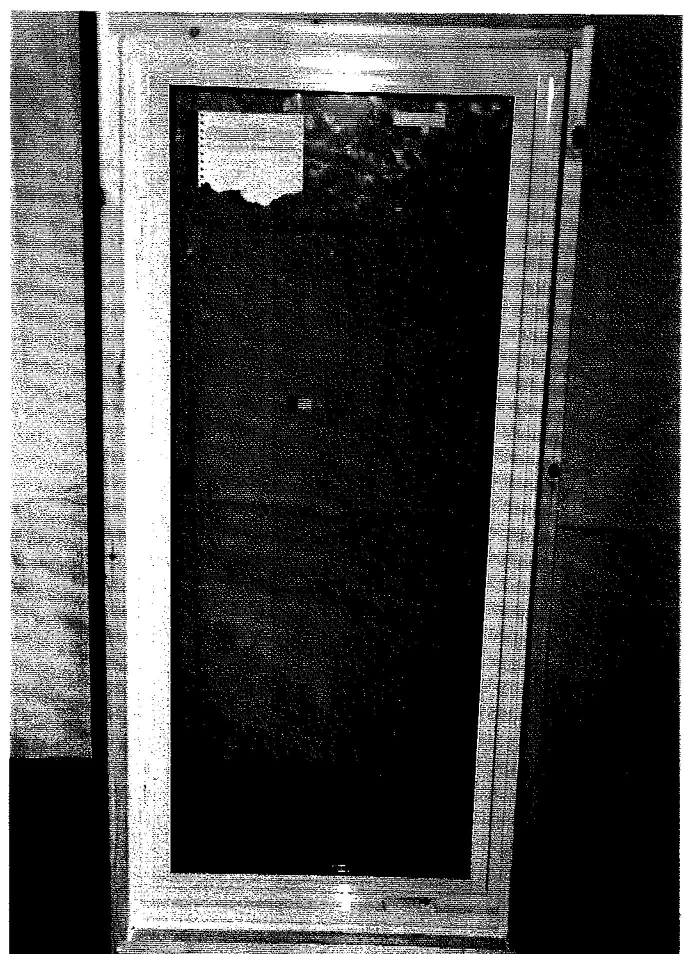
FRAME TO SUBFRAME ANCHORING:

The inside of each jamb of frame is attached to wooden subframe by three #8 - 2" screws.

SPECIMEN 12



Outside Elevation



Inside Elevation

SPECIMEN 12

TECHNICAL DESCRIPTION

WINDOW TYPE: Crank-operated casement
FRAME MATERIAL: Extruded aluminum with thermal break
OPERABLE SASH MATERIAL: Extruded aluminum and urethane foam
EXT. FRAME DIMENSIONS: 707 mm wide x 1600 mm high
EXT. SASH DIMENSIONS: 671 mm wide x 1556 mm high
CRACK LENGTH: 4.39 m
SNUBBER (AXIS OF ROTATION SIDE): None

SASH REINFORCEMENT: None

GLAZING:

TYPE:		CHARACTERISTICS:
_X_ DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: mm
_____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: Aluminum
	-	TOTAL THICKNESS: 28 mm

DESCRIPTION OF SEALING SYSTEM:

Double weatherstripping system. Outside sweep-type seal provided by pile/plastic fin strip attached to sash. Inside compression seal provided by two blades of flexible plastic attached to frame.

DESCRIPTION OF LOCKING SYSTEM:

Two cam latches. The locking points are positioned vertically at 270 mm and 1390 mm from bottom of sash.

FRAME TO SUBFRAME ANCHORING:

The insides of the frame jambs are attached using eight #8 - 2" screws. Four screws/jamb.

SPECIMEN 13

Outside Elevation

Inside Elevation

SPECIMEN 13

TECHNICAL DESCRIPTION

WINDOW TYPE: Crank-operated casement
FRAME MATERIAL: Extruded aluminum with thermal break
OPERABLE SASH MATERIAL: Extruded aluminum and urethane foam
EXT. FRAME DIMENSIONS: 714 mm wide x 1613 mm high
EXT. SASH DIMENSIONS: 664 mm wide x 1564 mm high
CRACK LENGTH: 4.39 m
SNUBBER (AXIS OF ROTATION SIDE): 3 pairs of snubbers located at 1/3, 1/2 and 2/3 of stile height.

SASH REINFORCEMENT: None

GLAZING:

TYPE:		CHARACTERISTICS:
X DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: 3 mm
____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: Swiggle strip
	-	TOTAL THICKNESS: 22 mm

DESCRIPTION OF SEALING SYSTEM:

Triple weatherstripping system. Outside sweep-style seal provided by pile strip attached to sash. Intermediate compression seal provided by bulb attached to sash. Inside compression seal provided by bulb attached to frame.

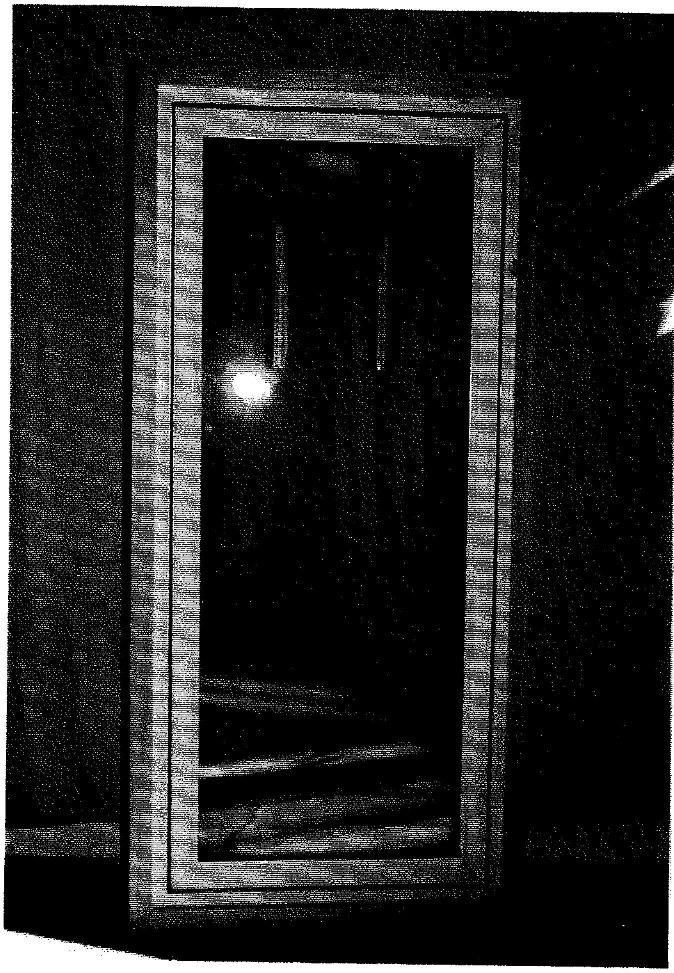
DESCRIPTION OF LOCKING SYSTEM:

Single lever multipoint (three locking points) system. The locks are positioned vertically at 240 mm, 790 mm and 1320 mm from the bottom of sash.

FRAME TO SUBFRAME ANCHORING:

Eight #8 - 2 1/2" screws across the thermal break. Three screws per jamb, one screw at head and one screw at sill.

SPECIMEN 14



Outside Elevation

Inside Elevation

SPECIMEN 14

TECHNICAL DESCRIPTION

WINDOW TYPE: Crank-operated casement
FRAME MATERIAL: Wood, aluminum cladding (exterior)
OPERABLE SASH MATERIAL: Aluminum exterior, PVC interior
EXT. FRAME DIMENSIONS: 702 mm wide x 1604 mm high
EXT. SASH DIMENSIONS: 643 mm wide x 1546 mm high
CRACK LENGTH: 4.37 m
SNUBBER (AXIS OF ROTATION SIDE): 2 pairs of snubbers located at 3/8 and 1111 mm from bottom of sash.

SASH REINFORCEMENT: None

GLAZING:

TYPE:		CHARACTERISTICS:
_X_ DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: 3 mm
_____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: Swiggle strip
	-	TOTAL THICKNESS: 20 mm

DESCRIPTION OF SEALING SYSTEM:

Double weatherstripping system. Outside sweep-style seal provided by pile/plastic fin strip attached to sash. Inside compression seal provided by flexible bulb attached to frame.

DESCRIPTION OF LOCKING SYSTEM:

Two cam latches. Locking points positioned vertically at 300 mm and 1225 mm from bottom of sash.

FRAME TO SUBFRAME ANCHORING:

Each jamb of frame is attached to the wood subframe by five #8 - 2 1/2" screws.

SPECIMEN 15

Outside Elevation

Inside Elevation

SPECIMEN 15

TECHNICAL DESCRIPTION

WINDOW TYPE: Tilt-turn
FRAME MATERIAL: Extruded PVC
OPERABLE SASH MATERIAL: Extruded PVC
EXT. FRAME DIMENSIONS: 701 mm wide x 1600 mm high
EXT. SASH DIMENSIONS: 625 mm wide x 1521 mm high
CRACK LENGTH: 4.24 m
SNUBBER (AXIS OF ROTATION SIDE): N/A

SASH REINFORCEMENT: Metal-reinforced stiles and rails.

GLAZING:

TYPE:		CHARACTERISTICS:
_X_ DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: 3 mm
____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: Aluminum
	-	TOTAL THICKNESS: 21 mm

DESCRIPTION OF SEALING SYSTEM:

Double weatherstripping system. Intermediate compression seal provided by flexible flange attached to frame. Inside compression seal provided by bulb attached to sash.

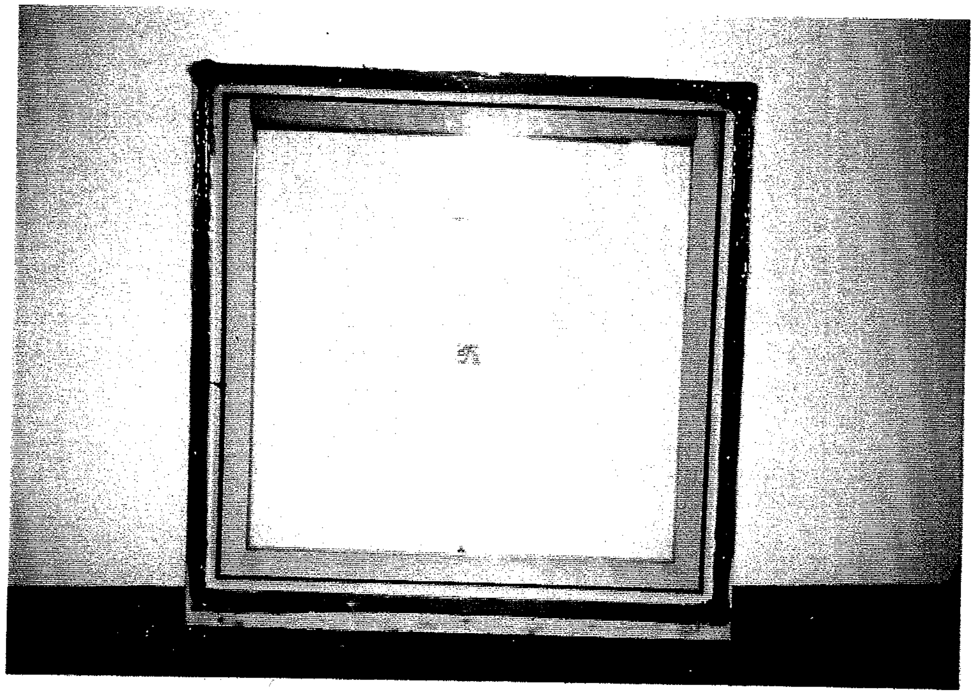
DESCRIPTION OF LOCKING SYSTEM:

Single handle (multipoint, five locking points) system. The locking points are positioned as follows: three on stile (axis of rotation side) at 85 mm, 880 mm and 1450 mm from bottom of sash.; one on stile (axis of rotation side) at 850 mm from bottom of sash; one on lower rail at 432 mm from corner of sash (handle side).

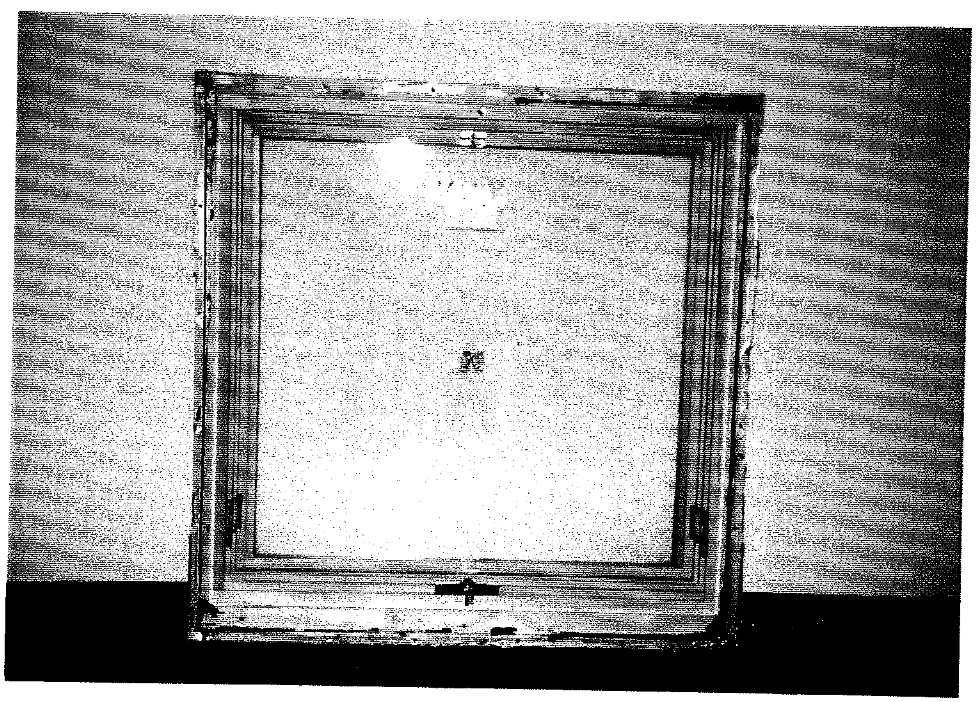
FRAME TO SUBFRAME ANCHORING:

Each jamb of the frame is screwed to the wooden subframe by three #8 - 1 1/2" screws.

SPECIMEN 16



Outside Elevation



Inside Elevation

SPECIMEN 16

TECHNICAL DESCRIPTION

WINDOW TYPE: Crank-operated awning
FRAME MATERIAL: Wood
OPERABLE SASH MATERIAL: Wood
EXT. FRAME DIMENSIONS: 1000 mm wide x 980 mm high
EXT. SASH DIMENSIONS: 930 mm wide x 950 mm high
CRACK LENGTH: 3.79 m
SNUBBER (AXIS OF ROTATION SIDE): None

SASH REINFORCEMENT: None

GLAZING:

TYPE:		CHARACTERISTICS:
_X_ DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: 3 mm
_____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: Aluminum
	-	TOTAL THICKNESS: 18 mm 0.725"

DESCRIPTION OF SEALING SYSTEM:

Single weatherstripping system. Outside sweep-type seal provided by two blades attached to sash.

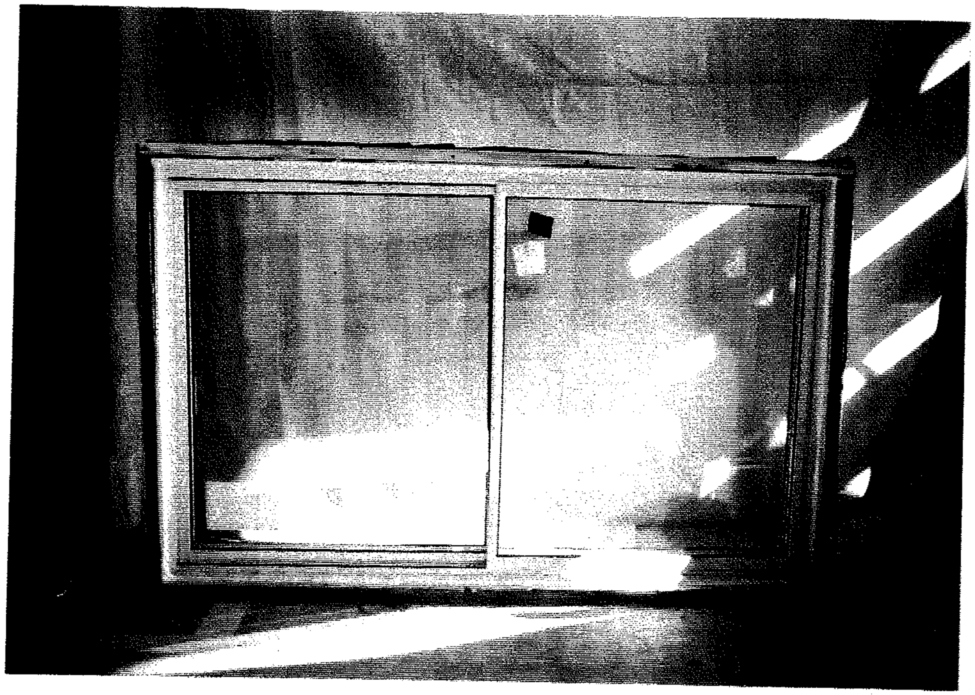
DESCRIPTION OF LOCKING SYSTEM:

One cam latch on each stile, positioned at 160 mm above bottom of sash.

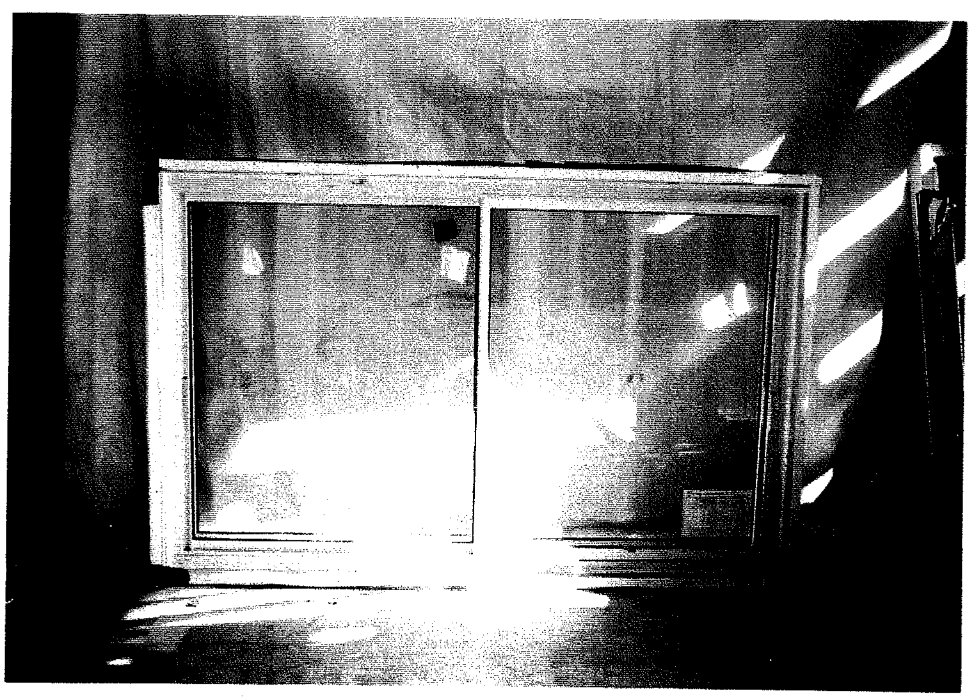
FRAME TO SUBFRAME ANCHORING:

Each jamb of the frame is screwed to the wooden subframe by four #8 - 2 1/2" screws. Two screws near head and two screws near sill.

SPECIMEN 17



Outside Elevation



Inside Elevation

SPECIMEN 17

TECHNICAL DESCRIPTION

WINDOW TYPE: Slider with four movable sashes
FRAME MATERIAL: Extruded aluminum with thermal break
OPERABLE SASH MATERIAL: Extruded aluminum
EXT. FRAME DIMENSIONS: 1612 mm wide x 1013 mm high
EXT. SASH DIMENSIONS: 789 mm wide x 951 mm high
CRACK LENGTH: 5.93 m
SNUBBER (AXIS OF ROTATION SIDE): N/A

SASH REINFORCEMENT: None

GLAZING:

TYPE:	CHARACTERISTICS:
_____ DOUBLE (FACTORY SEALED)	- THICKNESS OF GLASS: 3 mm
__X__ DOUBLE (SEPARATE SASH)	- SPACER TYPE: N/A
	- AIRSPACE: 58 mm

DESCRIPTION OF SEALING SYSTEM:

Sliding horizontal seal provided by a pile strip (with or without central polypropylene fin). Vertical sweep-style seal provided by a fin-pile strip.

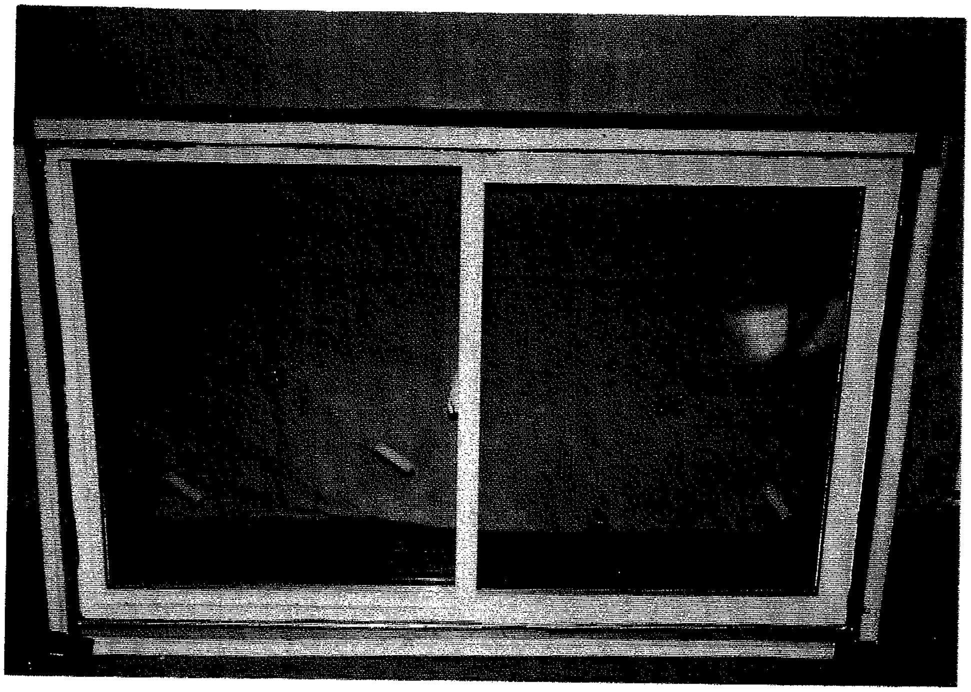
DESCRIPTION OF LOCKING SYSTEM:

One combination handle/lock at centre of operable stile on each sash.

FRAME TO SUBFRAME ANCHORING:

Inside of frame is screwed to wooden subframe by 10 #8 - 2" screws. Three screws at head, three screws at sill and two screws per jamb.

SPECIMEN 18



Outside Elevation

Inside Elevation

SPECIMEN 18

TECHNICAL DESCRIPTION

WINDOW TYPE: Slider with one movable pane and one fixed pane
FRAME MATERIAL: Extruded PVC
OPERABLE SASH MATERIAL: Extruded PVC
EXT. FRAME DIMENSIONS: 1600 mm wide x 1000 mm high
EXT. SASH DIMENSIONS: 792 mm wide x 951 mm high
CRACK LENGTH: 3.36 m
SNUBBER (AXIS OF ROTATION SIDE): N/A

SASH REINFORCEMENT: Metal-reinforced mullion

GLAZING:

TYPE:	CHARACTERISTICS:
_X_ DOUBLE (FACTORY SEALED)	- THICKNESS OF GLASS: 3 mm
_____ DOUBLE (SEPARATE SASH)	- SPACER TYPE: Aluminum
	- TOTAL THICKNESS: 25 mm

DESCRIPTION OF SEALING SYSTEM:

Single weatherstripping system provided by plastic-film-wrapped foam installed continuously around outside face of sash. Sliding horizontal seal. Sweep-style vertical seals.

DESCRIPTION OF LOCKING SYSTEM:

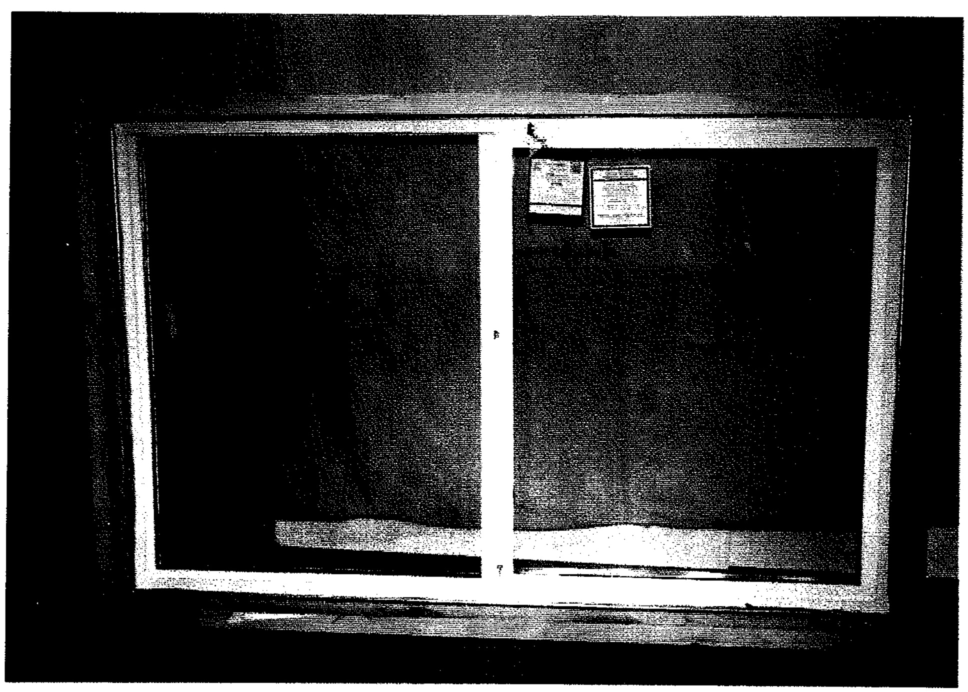
One sweep lock at centre of meeting stile.

FRAME TO SUBFRAME ANCHORING:

Three #8 - 2" screws at head and sill and two #8 - 2" screws per jamb.

SPECIMEN 19

Outside Elevation



Inside Elevation

SPECIMEN 19

TECHNICAL DESCRIPTION

WINDOW TYPE: Slider with one operable sash and one fixed sash
FRAME MATERIAL: Extruded PVC
OPERABLE SASH MATERIAL: Extruded PVC
EXT. FRAME DIMENSIONS: 1600 mm wide x 1004 mm high
EXT. SASH DIMENSIONS: 787 mm wide x 953 mm high
CRACK LENGTH: 3.44 m
SNUBBER (AXIS OF ROTATION SIDE): N/A

SASH REINFORCEMENT: None

GLAZING:

TYPE:		CHARACTERISTICS:
__X__ DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: 3 mm
_____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: Aluminum
	-	TOTAL THICKNESS: 25 mm

DESCRIPTION OF SEALING SYSTEM:

Single weatherstripping system provided by pile-fin seal continuous around outside face of sash. Sliding horizontal seal. Sweep-style vertical seal.

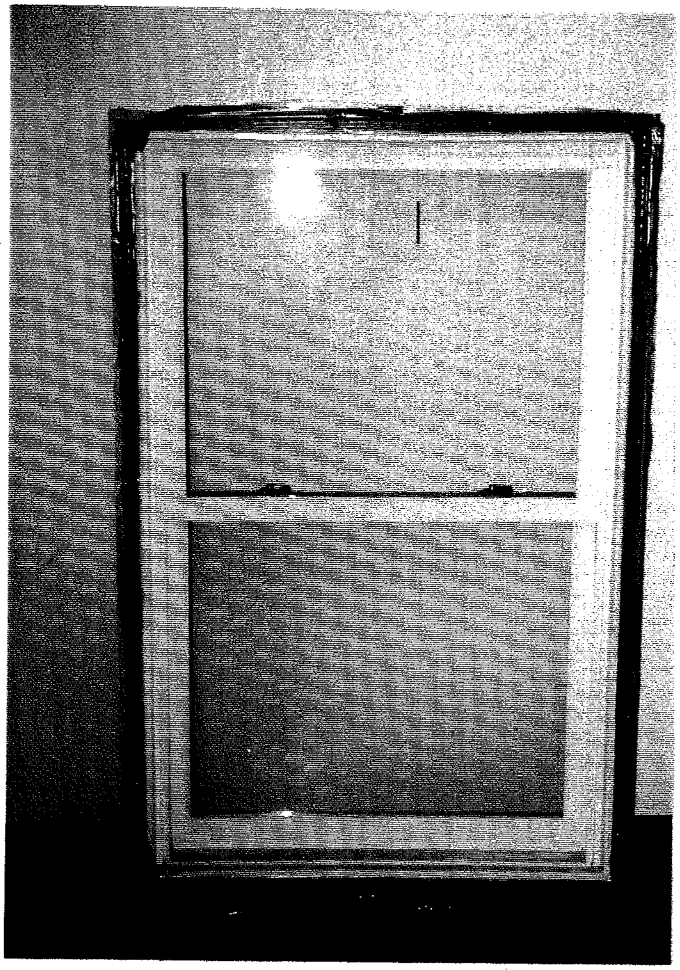
DESCRIPTION OF LOCKING SYSTEM:

One sweep lock at centre of meeting stile.

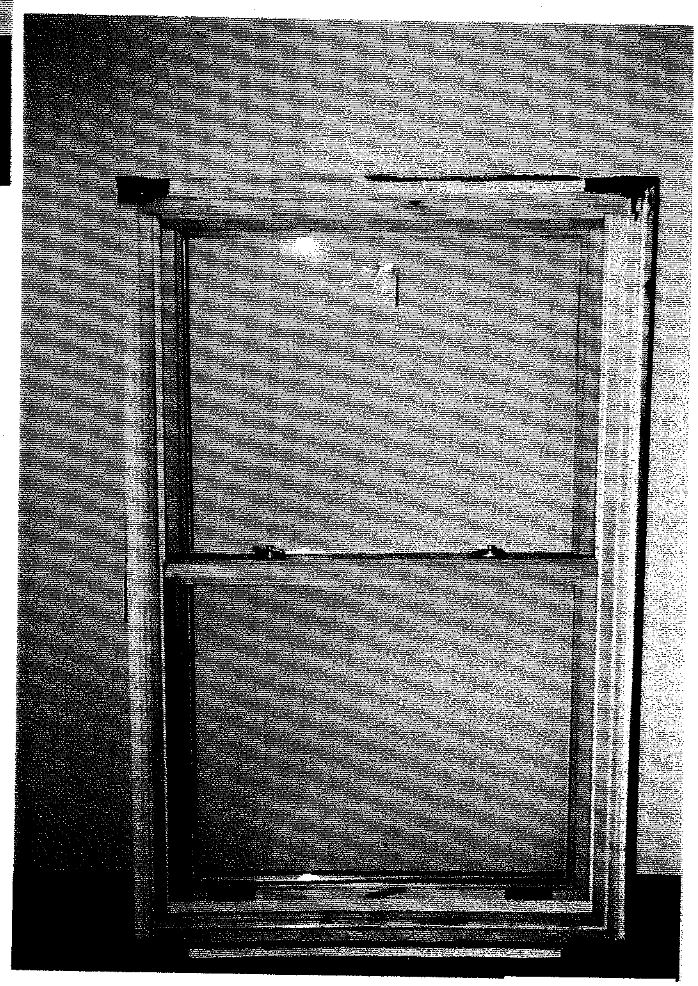
FRAME TO SUBFRAME ANCHORING:

Mounting flange extruded from frame is screwed to face of subframe using five #8 - 1 1/2" screws at head and sill and five #8 - 1 1/2" screws per jamb.

SPECIMEN 20



Outside Elevation



Inside Elevation

SPECIMEN 20

TECHNICAL DESCRIPTION

WINDOW TYPE: Double-hung vertical slider with two operable tilt-in sashes
FRAME MATERIAL: Wood and PVC
OPERABLE SASH MATERIAL: Wood, PVC cladding
EXT. FRAME DIMENSIONS: 1000 mm ["100 mm" in French original - Translator] wide x 1587 mm high
EXT. SASH DIMENSIONS: 928 mm wide x 780 mm high (lower sash)
x 774 mm high (upper sash)
CRACK LENGTH: 5.77 m
SNUBBER (AXIS OF ROTATION SIDE): N/A

SASH REINFORCEMENT: None

GLAZING:

TYPE:		CHARACTERISTICS:
_X_ DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: 3 mm
_____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: Aluminum
	-	TOTAL THICKNESS: 19 mm

DESCRIPTION OF SEALING SYSTEM:

All weatherstripping is made of plastic-film-wrapped foam, with the exception of the weatherstripping at the meeting stile which consists of two blades of flexible plastic. Sliding seal on sides of sash stiles. Compression seal on sash operating rails. Sweep-style seals on meeting stile and frame head and sill.

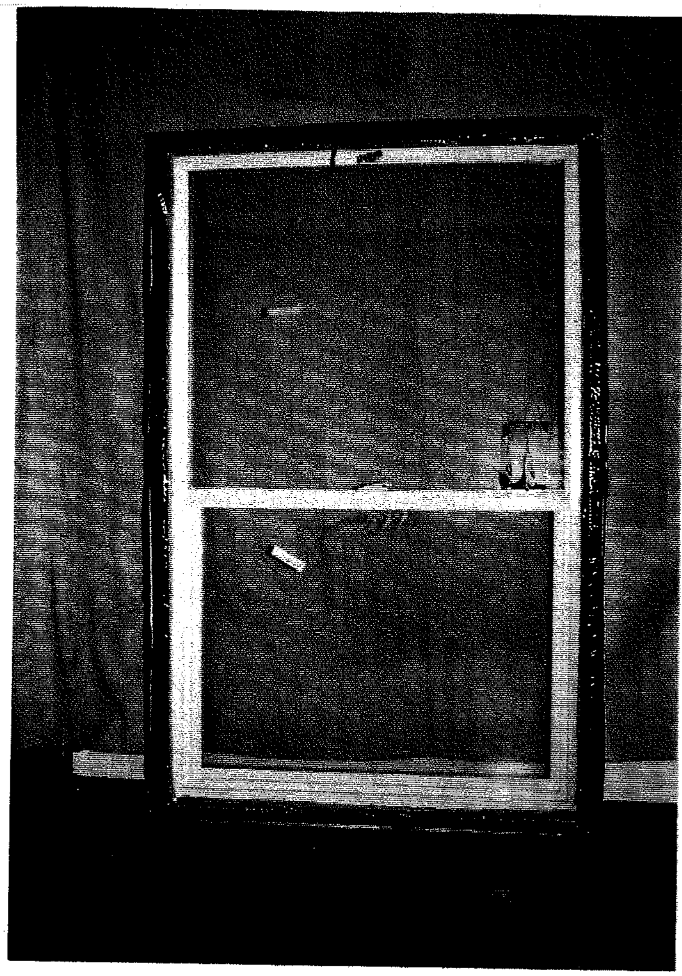
DESCRIPTION OF LOCKING SYSTEM:

Two sweep locks on meeting rails at 220 mm from each end.

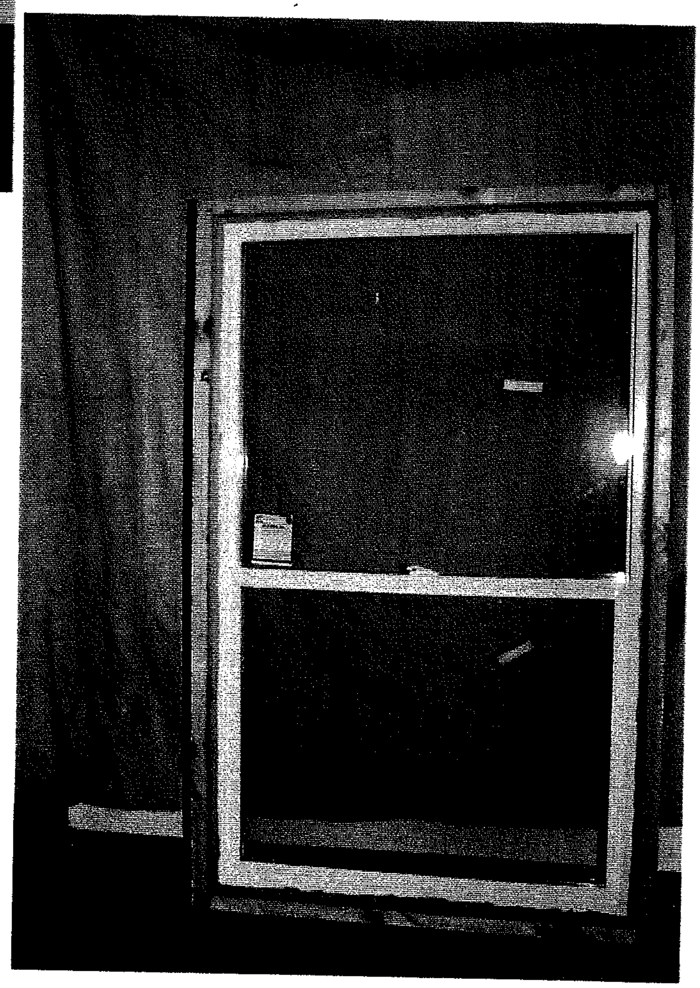
FRAME TO SUBFRAME ANCHORING:

Each jamb of the frame is screwed to the wooden subframe by five #8 - 2" screws. Two screws near sill, three others evenly spaced.

SPECIMEN 21



Outside Elevation



Inside Elevation

SPECIMEN 21

TECHNICAL DESCRIPTION

WINDOW TYPE: Double-hung vertical slider with one movable sash and one fixed sash
FRAME MATERIAL: Extruded PVC
OPERABLE SASH MATERIAL: Extruded PVC
EXT. FRAME DIMENSIONS: 1000 mm wide x 1600 mm high
EXT. SASH DIMENSIONS: 951 mm wide x 749 mm high
CRACK LENGTH: 3.30 m
SNUBBER (AXIS OF ROTATION SIDE): N/A

SASH REINFORCEMENT: Metal-reinforced mullion

GLAZING:

TYPE:		CHARACTERISTICS:
_X_ DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: 3 mm
_____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: Aluminum
	-	TOTAL THICKNESS: 25 mm

DESCRIPTION OF SEALING SYSTEM:

Single weatherstripping system consisting of plastic-wrapped-foam continuous around outside face of sash. Sweep-style horizontal seals. Sliding vertical seal.

DESCRIPTION OF LOCKING SYSTEM:

One sweep lock at centre of meeting rail.

FRAME TO SUBFRAME ANCHORING:

Three #8 - 2" screws per jamb and two #8 - 2" screws on sill.

SPECIMEN 22

Outside Elevation

Inside Elevation

SPECIMEN 22

TECHNICAL DESCRIPTION

WINDOW TYPE: Vertical slider with one operable tilt-in sash and one fixed sash
FRAME MATERIAL: Extruded PVC
OPERABLE SASH MATERIAL: Extruded PVC
EXT. FRAME DIMENSIONS: 1000 mm wide x 1600 mm high
EXT. SASH DIMENSIONS: 951 mm wide x 790 mm high
CRACK LENGTH: 3.49 m
SNUBBER (AXIS OF ROTATION SIDE): N/A

SASH REINFORCEMENT: None

GLAZING:

TYPE:		CHARACTERISTICS:
_X_ DOUBLE (FACTORY SEALED)	-	THICKNESS OF GLASS: 3 mm
_____ DOUBLE (SEPARATE SASH)	-	SPACER TYPE: Aluminum
	-	TOTAL THICKNESS: 25 mm

DESCRIPTION OF SEALING SYSTEM:

All weatherstripping consists of plastic-wrapped foam. Sliding seals on sash stiles (face and side). Sweep-style seal on sash rails (face). Compression seal on lower sash rail.

DESCRIPTION OF LOCKING SYSTEM:

One sweep lock at centre of meeting rail. One spring lock at each end of meeting rail.

FRAME TO SUBFRAME ANCHORING:

The mounting flange extruded from the frame is screwed to the face of the subframe by eight #8 - 2" screws per jamb and seven #8 - 2" screws at head and sill.

APPENDIX "B"

OBSERVATIONS

SPECIMEN 1	
WEATHER SIDE AIR TEMPERATURE	OBSERVATIONS
-30°C	Movement in upper corner of sash on lock side ≈ 2.5 mm. The other three corners are virtually stationary ≈ 0.5 mm. The frame remains straight.
0°C	Corners return to their former position ≈ 1 mm for upper corner on lock side.
50°C	Centre of sash stiles warp outwards. The movement measured is 2.2 mm on lock side and 1.4 mm on hinge side. The snubber in the middle of the hinge side stile reduces bowing.

SPECIMEN 2	
WEATHER SIDE AIR TEMPERATURE	OBSERVATIONS
-30°C to 50°C	No observable movement of sash with respect to frame. Members of sash and frame remain straight.

SPECIMEN 3	
WEATHER SIDE AIR TEMPERATURE	OBSERVATIONS
-30°C	Outward movement of approximately 1 mm, upper corner of sash (lock side).

SPECIMEN 5	
WEATHER SIDE AIR TEMPERATURE	OBSERVATIONS
-30°C	Slight outward curvature of frame and sash on lock side. Relative movement measured at sash extremities is approximately 2 mm.

SPECIMEN 6	
WEATHER SIDE AIR TEMPERATURE	OBSERVATIONS
-30°C	Outward movement of approximately 1 mm, upper corner of sash (lock side).

SPECIMEN 7	
WEATHER SIDE AIR TEMPERATURE	OBSERVATIONS
-30°C	Movement of approximately 3 mm of upper and lower corners of sash (lock side). As the cold air moves in around the perimeter of the sash, movement of corners tends to decrease. This causes the window airtightness to vary over time. The air infiltration rate given in the results is the rate measured in the first two minutes of testing. To observe sash behaviour, we maintained the temperature and pressure differentials for 45 minutes. The movement of sash corners was approximately 1.2 mm.

SPECIMEN 8	
WEATHER SIDE AIR TEMPERATURE	**OBSERVATIONS**
-30°C	Substantial (≈ 3 mm) outward movement of lower left corner of sash. Infiltration of cold air may be observed at this corner.

SPECIMEN 9	
WEATHER SIDE AIR TEMPERATURE	**OBSERVATIONS**
-30°C	Same window as specimen 8, except that intermediate and inside seals are of larger diameter. Movement of bottom left corner of the sash is the same, but cold air infiltration is considerably less.

SPECIMEN 10	
WEATHER SIDE AIR TEMPERATURE	**OBSERVATIONS**
-30°C	Same window as specimen 8, but with a different locking system. - Sash curvature is considerably less than in specimens 8 and 9. - Air infiltration observed mainly at locking points.

SPECIMEN 11	
WEATHER SIDE AIR TEMPERATURE	OBSERVATIONS
-30°C	- Movement of 3.5 mm, upper corner of sash, lock side. - Movement of 2 mm, lower corner of sash, lock side. - Centre of sash stile on axis of rotation side moves approximately 1 mm inward. - Sash has a tendency to recover (movement of corners diminishes) with infiltration of cold air, causing a variation in the airtightness over time. The air infiltration rate given in the results is the rate measured in the first two minutes of testing. - Frame also bows approximately 1 mm (axis of rotation side).
0°C	- Movement of 2.2 mm, upper corner of sash, lock side. - Movement of 0.5 mm, lower corner of sash, lock side. - Slight curvature (< 1 mm) of sash stile, axis of rotation side. - The sash recovery phenomenon associated with infiltration of cold air is also observed at 0°C, but the pressure differential must be applied for a longer time period before any difference in airtightness is observed (approximately four minutes).

SPECIMEN 9	
WEATHER SIDE AIR TEMPERATURE	**OBSERVATIONS**
-30°C	Lock side: Movement of upper corner of sash: approximately 2.5 mm in relation to frame. Movement of lower corner of sash: approximately 0.5 mm in relation to frame. Movement of centre of sash stile: approximately 1 mm inward in relation to frame. Movement of frame extremities: approximately 1.5 mm (tends to follow sash). Axis of rotation side: Inward movement of centre of stile: approximately 1 mm.

SPECIMEN 13	
WEATHER SIDE AIR TEMPERATURE	**OBSERVATIONS**
-30°C	Outward movement (approximately 2 mm) of upper and lower sash extremities (lock side).

SPECIMEN 14	
WEATHER SIDE AIR TEMPERATURE	OBSERVATIONS
-30°C	- Members of sash and frame remain straight. - Primary seal (bulb) becomes rigid. (This may explain the increase in leakage at low temperature) - Substantial air infiltration was observed in the following places: upper corner (lock side), around locks and lower corner (lock side).

SPECIMEN 15	
WEATHER SIDE AIR TEMPERATURE	OBSERVATIONS
-30°C	The most substantial movement of the sash in relation to the frame was measured at the centre of the stile on the axis of rotation side (0.6 mm).

SPECIMEN 16	
WEATHER SIDE AIR TEMPERATURE	OBSERVATIONS
-30°C to 50°C	No movement of sash in relation to frame observed. Members of frame and sash are straight.

SPECIMEN 17	
WEATHER SIDE AIR TEMPERATURE	OBSERVATIONS
	No specific phenomenon observable at any test temperature.

SPECIMEN 18	
WEATHER SIDE AIR TEMPERATURE	OBSERVATIONS
-30°C	Curvature (in plane perpendicular to glass) of sash rail midpoint in relation to ends: 1.5 mm for upper rail 1.0 mm for lower rail

SPECIMEN 19	
WEATHER SIDE AIR TEMPERATURE	OBSERVATIONS
-30°C	Frame side sash stile very slightly curved outward.

SPECIMEN 20	
WEATHER SIDE AIR TEMPERATURE	OBSERVATIONS
-30°C	- Sash stiles show slight outward curvature, approximately 0.5 mm. - Air infiltration is felt mainly at the meeting rail.

SPECIMEN 21	
WEATHER SIDE AIR TEMPERATURE	OBSERVATIONS
-30°C	Note: Meeting rail of movable sash was initially curved upward by approximately 4 mm (weight probably excessive). - Outward curvature of sash members (approximately 1.5 mm). - Substantial infiltration of air at weight extremities.

SPECIMEN 22	
WEATHER SIDE AIR TEMPERATURE	OBSERVATIONS
-30°C	Weatherstrip installed on sides of sash stile no longer provide satisfactory contact with the frame.