A Study OF THE LONG TERM PERFORMANCE OF OPERATING AND FIXED WINDOWS SUBJECTED TO PRESSURE CYCLING

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CANMET Energy Technology Centre
Energy Technology Branch, Energy Sector
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PREPARED BY:

AIR-INS inc.
1320, boulevard Lionel Boulet
Varennes, Québec, Canada,J3X 1P8
Phone: (450) 652-0838; Fax: (450) 652-7588
Email: aipcinc@total.net

SCIENTIFIC AUTHORITY

Joël Allarie
The CANMET Energy Technology Centre
Energy Technology Branch, Energy Sector
Department of Natural Resources Canada
580 Booth Street, 13th Floor
Ottawa, Ontario, Canada
K1A 0E4

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FOREWORD

This project determines the influence of pressure cycling on ten (10) windows for the following performance criteria: ease of operation, air leakage, resistance to water penetration and condensation resistance.

Windows are subjected to a total of 2000 pressure cycles composed of two initial pressure cycling intervals of 500 cycles and a final pressure cycling interval of 1000 cycles. Before or after each interval, one or several performance criteria are checked.

The pressure cycling test showed that for all specimens there was a decrease in one or several of the performance criterion covered by the CAN/CSA-A440-M90 Standard. The variation of operating forces from initial to final testing ranged from +23% to +194%. After 2000 cyles, all specimens showed an increase in the air leakage rate ranging from 8% to 275%. With respect to resistance to water penetration, 8 specimens kept their initial rating whereas the remaining 2 specimens suffered a decrease of 1 or 2 levels of performance after 2000 cycles. For the condensation resistance criteria most specimens showed a decrease of the temperature index ranging from 2 to 30 points. Among all the criteria, condensation resistance is the criterion which suffered the largest decrease in performance from initial to final testing.

Beside providing data with respect to the influence of pressure cycling, this project showed that condensation resistance tests conducted on some non-metallic windows (wood and PVC) lead to an initial temperature index which does not meet the minimum performance level specified by the A440 Standard.

PREAMBULE

La présente étude détermine l'influence d'un essai de cyclage de la pression sur 10 fenêtres. Les critères d'évaluation utilisés pour caractériser l'influence de l'essai de cyclage sont: la facilité de fonctionnement, l'infiltration d'air, la résistance à la pénétration d'eau et la résistance à la condensation.

Chaque fenêtre a été soumise à un total de 2000 cycles, lequel est subdivisé en deux intervals initiaux de 500 cycles et un interval final de 1000 cycles. Avant ou après chaque interval un ou plusieurs critères d'évaluation sont vérifiés.

L'essai de cyclage de la pression a démontré que toutes les fenêtres ont subi une diminution d'un ou plusieurs niveaux de performance dans la classification d'un produit selon la norme CAN/CSA-A440-M90. L'effort requis pour opérer les ouvrants a varié de +23% à +194% entre le début et la fin de l'essai de cyclage. En ce qui concerne l'infiltration d'air, tous les échantillons ont subi une augmentation du taux d'infiltration d'air variant de +8% à +275% entre le début et la fin de l'essai d'endurance. Pour le critère résistance à la pénétration d'eau, 8 échantillons ont conservé leur classification de base, alors que 2 échantillons ont subi une diminution de classe de 1 niveau après 2000 cycles. Pour le critère de résistance à la condensation, la plupart des échantillons ont subi une baisse de l'indice de température variant de 2 à 30 points. Parmis tous les critères évalués, la résistance à la condensation est certainement le critère qui est le plus influencé par l'essai de cyclage de la pression.

En plus de fournir des données utiles visant l'influence d'un essai de cyclage de la pression sur 4 critères d'évaluation, le projet a permis de constater que certaines fenêtres avec menuiserie non-métallique (bois, PVC) ne rencontre pas l'exigence minimale de résistance à la condensation spécifiée par la norme A440.

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TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

1.1 OBJECTIVES

Windows installed in building façades are subjected to wind of fluctuating directions and intensities. This project undertakes to determine the influence of pressure cycling on windows for the following criteria of performance: ease of operation (if applicable), air leakage, resistance to water penetration and condensation resistance. Even though ease of operation and resistance to water penetration are not related to energy conservation, the level of performance of these criteria have to be maintained throughout the life of the product since they have an important impact on the durability of the window system. As such, they were evaluated.

1.2 SAMPLING

Pressure cycling tests were conducted on ten windows. Sampling included the following window types: casement, vertical sliding, horizontal sliding and fixed windows. Table A gives a brief description of each window with respect to the frame material.

TABLE A: WINDOW TYPES AND IDENTIFICATION

TYPE OF WINDOW	IDENTIFICATION NUMBER OF THE SPECIMENS (FRAME)			
CASEMENT (700 mm x 1600 mm)	PC-9 (PVC) *	PC-10 (PVC)	PC-15 (WOOD)	PC-17 (WOOD)
VERTICAL SLIDER (1000 mm x 1600 mm)	PC-1 (AL) **	PC-11 (PVC)	PC-18 (WOOD)	
HORIZONTAL SLIDER (1600 mm x 1000 mm)	PC-8 (PVC)			
FIXED (2000 mm x 2000 mm)	PC-13 (PVC)	PC-16 (WOOD)		

* PVC: Polyvinyl chloride
* AL : Aluminum

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1.3 METHODOLOGY

All specimens were subjected to the following test sequence:

a) Find the initial ratings (R_o) with respect to the following criteria; ease of operation, air leakage, resistance to water penetration and condensation resistance;

b) Conduct 500 pressure cycles between + 1.2 kPa and -1.2 kPa in accordance with ASTM E1233-88;

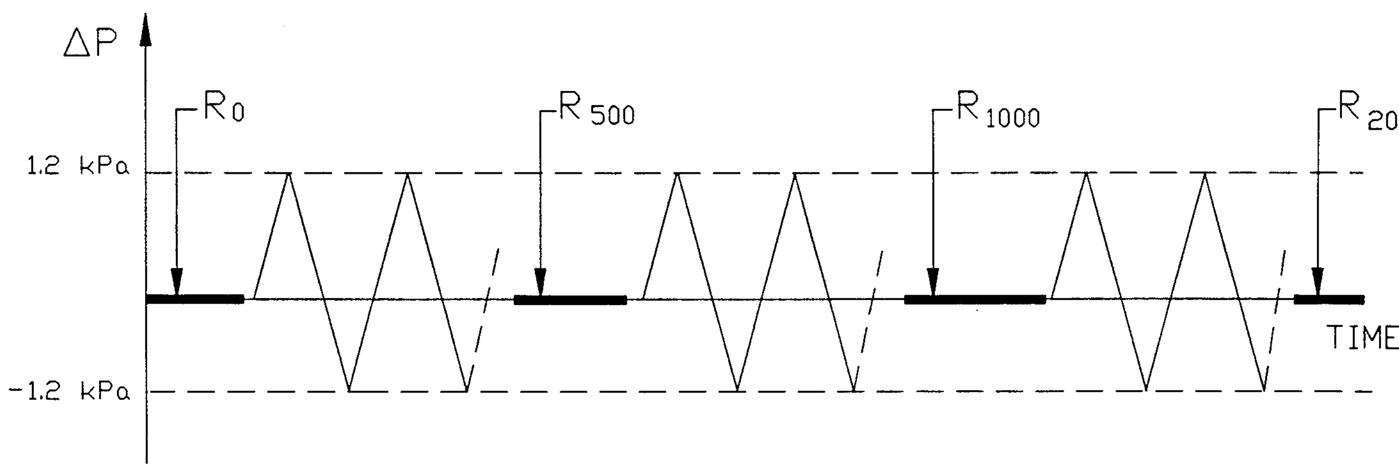
c) Determine new rating (R_{500}) with respect to ease of operation and air leakage;

d) Conduct an additional 500 pressure cycles as defined in (b);

e) Determine new rating (R_{1000}) with respect to ease of operation, air leakage and resistance to water penetration;

f) Conduct an additional 1000 pressure cycles as defined in (b);

g) Determine new rating (R_{2000}) with respect to ease of operation, air leakage resistance to water penetration and condensation resistance.



1.4 RESULTS

Tables B, C, D and E summarize the changes in performance which occured on each specimen throughout the complete test sequence.

TABLE B: EASE OF OPERATION

TYPE AND SPECIMEN NUMBER	INITIAL				2000 CYCLES				% VARIATION IN FORCE (%)
	STATIC N (lb)		DYNAMIC N (lb)		STATIC N (lb)		DYNAMIC N (lb)		
	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE	
CASEMENT									
PC-9 (PVC)	24.5 (5.5)	40 (9)	11.1 (2.5)	11.1 (2.5)	80.1* (18)	44.5 (10)	31.1* (7)	22.2 (5)	+ 129.6
PC-10 (PVC)	12.5 (2.8)	14.2 (3.2)	6.7 (1.5)	6.7 (1.5)	53.4 (12)	35.6 (8)	11.12 (2.5)	22.2 (5)	+ 193.8
PC-15 (WOOD)	22.2 (5)	26.7 (6)	6.7 (1.5)	13.3 (3)	35.6 (8)	26.7 (6)	8.9 (2)	13.3 (3)	+ 23.3
PC-17 (WOOD)	45.8 (10.3)	19.1 (4.3)	10.2 (2.3)	8.9 (2)	44.5 (10)	37.8 (8.5)	8.9 (2)	13.3 (3)	+ 32.9
VERTICAL SLIDER									
PC-1 (AL)	164.6 (37)	155.7 (35)	148.8* (33)	89 (20)	169 (38)	111.2 (25)	137.9* (31)	75.6 (17)	- 11.8
PC-11 (PVC)	160 (36)	151.2 (34)	106.8* (24)	102.3* (23)	177.9 (40)	160.1 (36)	106.8* (24)	106.8* (24)	+ 36.2
PC-18 (WOOD)	131.2 (29.5)	111.2 (25)	124.6* (28)	64.5 (14.5)	106.8 (24)	160.1 (36)	164.6* (37)	146.79* (33)	+ 46.3
HORIZONTAL SLIDER									
PC-8 (PVC)	35.6 (8)	48.9 (11)	44.5 (10)	62.3* (14)	62.3* (14)	66.7 (15)	53.4* (12)	57.8* (13)	+ 31.0

* Exceeds the maximum allowable force specified by the A440 Standard.

TABLE C: AIR LEAKAGE

TYPE AND SPECIMEN	INITIAL m^3/h-m (SCFM/ft)	500 CYCLES m^3/h-m (SCFM/ft)	1000 CYCLES m^3/h-m (SCFM/ft)	2000 CYCLES m^3/h-m (SCFM/ft)	δQ	
					ABSOLUTE m^3/h-m (SCFM/ft)	%
CASEMENT						
PC-9 (PVC)	0.424-A3 (0.076)	0.663-A2 (0.119)	0.735-A2 (0.132)	1.541-A2 (0.2766)	1.117 (0.201)	+ 263
PC-10 (PVC)	1.042-A2 (0.187)	1.174-A2 (0.211)	1.087-A2 (0.195)	1.126-A2 (0.202)	0.084 (0.015)	+ 8.1
PC-15 (WOOD)	0.279-A3 (0.050)	0.312-A3 (0.056)	0.303-A3 (0.054)	0.55-A3 (0.099)	0.271 (0.049)	+ 97.1
PC-17 (WOOD)	0.518-A3 (0.093)	0.531-A3 (0.095)	0.531-A3 (0.095)	0.640-A2 (0.115)	0.122 (0.022)	+ 23.6
VERTICAL SLIDER						
PC-1 (AL)	1.020-A2 (0.183)	1.143-A2 (0.205)	1.07-A2 (0.192)	1.443-A2 (0.259)	0.423 (0.076)	+ 41.5
PC-11 (PVC)	1.95-A1 (0.35)	6.814* (1.223)	7.061* (1.267)	7.323* (1.314)	5.373 (0.964)	+ 275.4
PC-18 (WOOD)	0.736-A2 (0.132)	0.978-A2 (0.175)	0.943-A2 (0.169)	0.920-A2 (0.165)	0.184 (0.033)	+ 25
HORIZONTAL SLIDER						
PC-8 (PVC)	2.563-A1 (0.460)	2.570-A1 (0.461)	2.600-A1 (0.467)	2.814* (0.505)	0.251 (0.045)	+ 9.8
FIXED						
PC-13 (PVC)	0.141-FIXED (0.0253)	0.162-FIXED (0.0290)	0.173-FIXED (0.031)	0.173-FIXED (0.031)	0.032 (0.0057)	+ 2.27
PC-16 (WOOD)	0.0167-FIXED (0.003)	0.0167-FIXED (0.003)	0.020-FIXED (0.0036)	0.0232-FIXED (0.0042)	0.0065 (0.0012)	+ 39

* Exceeds the maximum allowable air leakage specified by the A440 Standard.

TABLE D: RESISTANCE TO WATER PENETRATION

TYPE AND SPECIMEN NUMBER	INITIAL	1000 CYCLES	2000 CYCLES
CASEMENT			
PC-9 (PVC)	B3	B3	B3
PC-10 (PVC)	B2	B2	B2
PC-15 (WOOD)	B2	B2	B2
PC-17 (WOOD)	B3	B3	B3
VERTICAL SLIDER			
PC-1 (AL)	B1	B1	B1
PC-11 (PVC)	B2	B1	B 1/2* (75 Pa)
PC-18 (WOOD)	B7	B6	B6
HORIZONTAL SLIDER			
PC-8 (PVC)	B 1/2* (75 Pa)	B 1/2* (75 Pa)	B 1/2* (75 Pa)
FIXED			
PC-13 (PVC)	B3	B3	B3
PC-16 (WOOD)	B7	B7	B6

* Lower than the minimum acceptable level of A440

TABLE E: TEMPERATURE INDEX (CONDENSATION RESISTANCE)

TYPE AND SPECIMEN NUMBER	INITIAL		2000 CYCLES	
	TI_G	TI_F	TI_G	TI_F
CASEMENT				
PC-9 (PVC)	60	52	54	22*
PC-10 (PVC)	60	18*	54	16*
PC-15 (WOOD)	58	48	54	52
PC-17 (WOOD)	60	38*	58	40
VERTICAL SLIDER				
PC-1 (AL)	62	50	60	40
PC-11 (PVC)	60	10*	56	12*
PC-18 (WOOD)	60	32*	58	34*
HORIZONTAL SLIDER				
PC-8 (PVC)	60	40	58	40
FIXED				
PC-13 (PVC)	58	58	58	56
PC-16 (WOOD)	56	58	60	58

* TI lower than minimum acceptable value specified by A440 (TI = 40)

* TI_G: Glass temperature index

* TI_F: Frame temperature index

1.5 CONCLUSIONS

1.5.1 EASE OF OPERATION

Except for the aluminum vertical sliding window (PC-1), all specimens showed an increase in the operating forces to initiate and to maintain motion of sashes. The increase ranged from 23% to 194%. PVC casement windows (PC-9 and PC-10) showed the highest increase in the operating forces.

1.5.2 AIR LEAKAGE

All specimens showed an increase in the air leakage rate ranging from 8% to 275%.

The largest increase were met on two PVC windows (PC-9 and PC-11). Most of the air leakage increases seem to be caused by a combination of the following factors; compression set of weatherstripping, creeping of PVC sash members during pressure cycling and the lack of rigidity of sash members.

1.5.3 RESISTANCE TO WATER PENETRATION

The resistance to water penetration of most specimens did not change from the initial value.

Only two windows (PC-11 and PC-16) suffered a decrease in rating.

1.5.4 CONDENSATION RESISTANCE (TEMPERATURE INDEX)

Even though the condensation resistance test is not mandatory for PVC and wood windows (A440), the testing showed that even if the framing material is a poor heat conductor (or a good insulator), the interior frame surface temperatures can be lower than the minimum acceptable level (TI = 40). Such low surface temperatures can only be attributed to cracks that must have developed between sash and frame members when the windows were subjected to a large temperature differential.

Upon completion of the pressure cycling test, the glass temperature index (TI_G) remained nearly identical to the initial value. Nevertheless, the same pressure cycling test introduced on some windows a large decrease (δ = 30 points) of the frame temperature index (TI_F). Here again, such a decrease in performance level can only be attributed to cracks that may develop between sash and frame members.

1.6 RECOMMANDATIONS

- The pressure cycling test showed that in most cases there was a decrease in one or several of the performance criteria covered by the A440 Standard. To ensure durability of new windows, this new criteria of pressure cycling with the test procedure should be incorporated into the main boby of the Canadian standard.
- The condensation resistance tests conducted on non-metallic windows (wood and PVC) showed that some of these new products did not meet the minimum performance level specified by the A440 Standard, even when new. Therefore, in order to make it fair for all framing materials, the evaluation of this criteria should be made mandatory for all materials.
- To improve the certainty of the performance levels given by the CCMC accreditation, manufacturers should make random inspection for quality control aspects during the manufacturing process and an independant certification system should be put in place.

2. INTRODUCTION

Even though operating windows are evaluated as new products, it does not ensure that their performance is maintained with respect to time. With respect to energy conservation this may translate into higher energy consumption which may be caused by an increase in air infiltration rates which may in turn be due to premature deterioration of weatherstripping, hardware, etc. In addition, higher air infiltration rates will also reduce the condensation resistance of windows and accelerate the deterioration of the assembly and surrounding components. In fact, the durability and the long term performance of the entire window system will be affected.

To alleviate the durability problems and improve the long term performance of operating windows, the behavior of existing products need to be determined and criteria of acceptance for incoming new products needs to be established.

This project undertakes to determine the influence of pressure cycling on the following criteria of performance: ease of operation, air leakage, resistance to water penetration and condensation resistance. Even though ease of operation and resistance to water penetration are not related to energy conservation, their respective levels of performance have to be maintained throughout the life of the product since they have an important impact on the durability of the window system. As such, they need to be evaluated.

2.1 Description of specimens

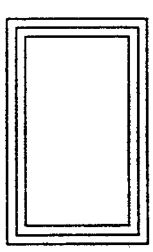
Table 1 below indicates the windows tested.

Table 1: Window Types and Identification

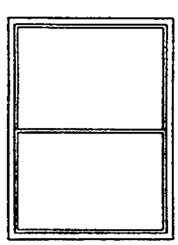
TYPE OF WINDOW	IDENTIFICATION NUMBER OF THE SPECIMENS (FRAME)			
CASEMENT (700 mm x 1600 mm)	PC-9 (PVC)*	PC-10 (PVC)	PC-15 (Wood)	PC-17 (Wood)
VERTICAL SLIDER (1000 mm x 1600 mm)	PC-1 (Al)*	PC-11 (PVC)	PC-18 (Wood)	
HORIZONTAL SLIDER (1600 mm x 1000 mm)	PC-8 (PVC)			
FIXED (2000 mm X 2000 mm)	PC-13 (PVC)	PC-16 (Wood)		

* PVC = Polyvinyl chloride
* Al = Aluminum

Total number of specimens: 10



Casement



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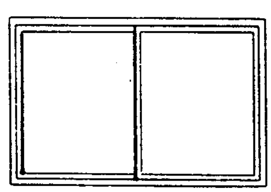
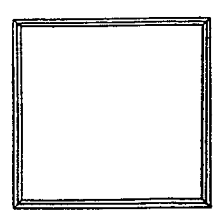


Horizontal Slider



FIXED

A detailed description of each specimen (weatherstripping, dimensions, etc...) is given in Appendix A.

2.2 Description of test apparatus

In order to undertake this study cycling air pressure system was to be designed and constructed for the testing of exterior windows, curtain walls, and doors for structural fatigue under cyclic wind loads as per ASTM Standard Test Method E 1233-88. This test consists of the application of a given number of cycles of positive/negative static pressure differential across the test specimen with subsequent checks of the specimen for signs of fatigue. Due to the lengthy nature of this test, the cycling air pressure system was to be fully automatic in its cycling.

A cycling air pressure system was conceived which used a blower to provide static air pressure to a test chamber. This test chamber would have an opening on one side against which the test specimen would be sealed. An intermediate component connected between these two would be used to cycle the blower's flow to the test chamber. Blowers and test chambers of this type were already in use to perform other window tests and were readily available (Fig. 1a). As a result, only the intermediate cycling component was required to be designed and constructed. This component is kown as the cyclic air pressure delivery device (Fig. 1b).

The cyclic air pressure delivery device uses four flow-direction valves to control the direction of the air flow to the test chamber and hence, the sign (positive or negative) of the test chamber pressure. Two sets of throttling valves are used to independently control the magnitudes of the positive and negative test chamber pressures. The four flow-direction valves are pneumatically actuated so that their configuration may be controlled by a programmable logical controller (PLC) to allow for automatic pressure cycling. In an initialization procedure at the beginning of the test, the positive and negative test pressures are manually set using the throttling valves. The PLC is then programmed for the desired number of cycles and the device automatically cycles the test chamber pressure until this number is reached.

The cyclic air pressure delivery device, therefore, allows the user to perform ASTM Standard Test Method E 1233-88 without the need for supervision during the cycling process, after the completion of a simple initialization procedure.

NOTE: See Appendix "B" for a detailed description of the test apparatus.

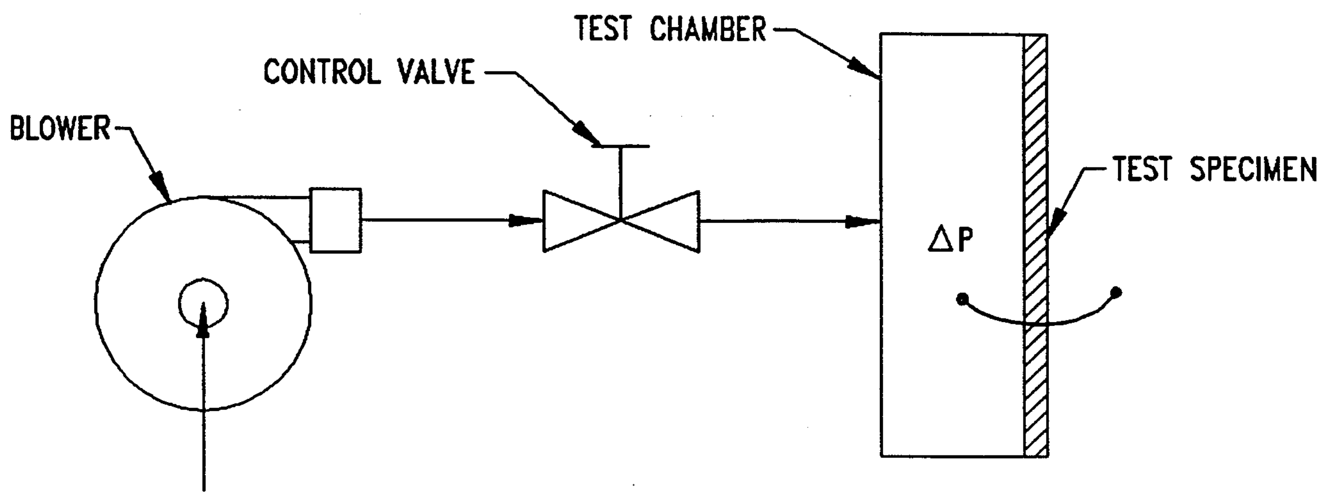


FIGURE 1a. Schematic of a wind load resistance test apparatus.

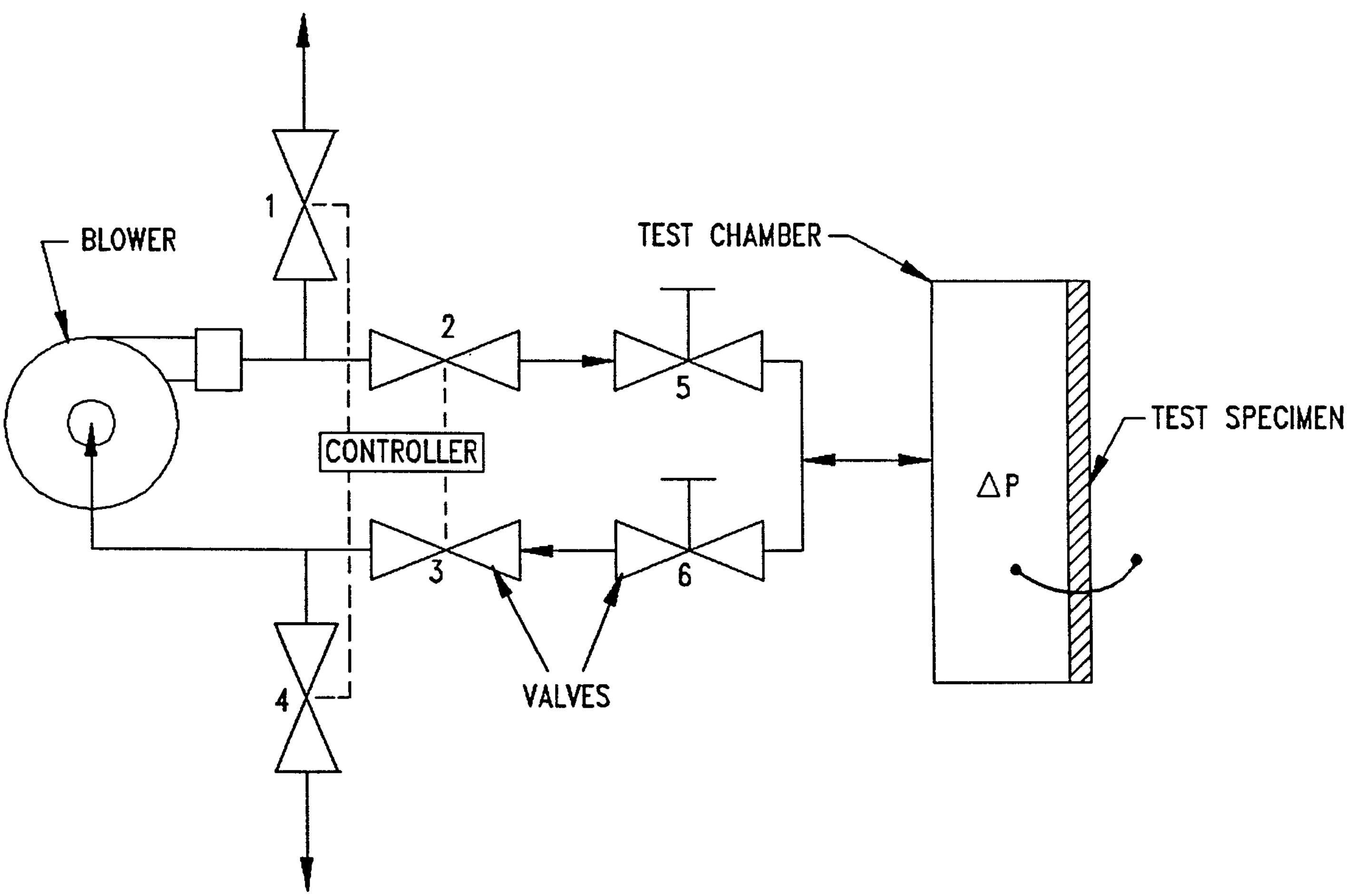


FIGURE 1b. Schematic of the cycling air pressure test apparatus.

3. METHODOLOGY

The test consisted of cycling the pressure on each specimen and evaluating the level of performance of the four criteria after a predetermine number of cycles as listed in table 2. All tests (see 3.1) were conducted in accordance with the testing procedures and methods stated in the CAN/CSA-A440-M90 nation window standard.

TABLE 2: PERFORMANCE CHECK

NUMBER OF CYCLES	EVALUATION OF PERFORMANCE LEVEL			
	EASE OF OPERATION	AIR LEAKAGE (INF. & EXF)	WATER PENETRATION	CONDENSATION RESISTANCE
0	X	X	X	X
500	X	X		
1000	X	X	X	
2000	X	X	X	X

3.1 Description of test procedure

The test performed on the specimens are described in the following sections, in accordance with the CAN/CSA-A440-M90 standard.

3.1.2 Ease of Operation

With the window mounted on a suitable test frame, the operable light(s) shall be moved from the fully closed to the fully open position and back at least three times, to ensure that the light is operating freely. Such adjustments as might easily be performed in the field during normal installation may be made.

Using a spring balance or other suitable device* calibrated in units no larger than 5 N, the force required to initiate motion of the operable light(s) from both the fully closed and fully open positions shall be measured, as well as the force required to maintain motion to the opposite limits of travel. The point of application, direction, and maximum acceptable value of such force shall be as indicated in Table 3.

TABLE 3: EASE OF OPERATION

TYPE OF WINDOW	POINT OF APPLICATION OF FORCE	DIRECTION OF FORCE	MAXIMUM FORCE TO INITIATE MOTION, N (lb)	MAXIMUM FORCE TO MAINTAIN MOTION, N (lb)
Vertically sliding	Midpoint of operating handle(s) or of meeting rail	Vertical, parallel to plane of glass	200 (45)	100 (22.5)
Horizontally sliding	Midpoint of operating handle(s) or of meeting rail	Horizontal parallel to plane of glass	90 (20.5)	45 (10.1)
Casement and projecting with roto-operators	End of crank handle	Perpendi- cular to crank handle and screw	60 (13.5)	30 (6.75)

* When testing windows with roto-operators, it is recommended that the torque, T, necessary to initiate and maintain motion be measured. This may then be converted to force (F) values using the centre-to-centre length of the lever, L, in the equation $F = T/L$.

3.1.3 Air infiltration test

Windows are rated with respect to the rate of air infiltration per unit length of crack of the specimen when the window is subjected to a static pressure differential of 75 Pa (1.56 lb/ft.^{2}). Such a pressure differential is equivalent to the pressure exerted by a wind having a velocity of 40 km/h (25 mi/h). The test is performed in accordance with A.S.T.M. E-283-84 specification. The window rating or classification is given in Table 4 below.

TABLE 4: WINDOW CLASSIFICATION FOR AIR LEAKAGE

WINDOW RATING	MAXIMUM AIR LEAKAGE RATE PER UNIT LENGTH OF CRACK AT P=75 Pa (1.56 lb/ft^2)	
	m^3/h-m	(ft^3/min-ft)
A1	2.79	0.5
A2	1.65	0.3
A3	0.55	0.1
FIXED	0.25	0.045

3.1.4 Water resistance test

Windows are rated with respect to the highest static pressure differential sustained with success by the specimen during a given test period. The window classification is given in Table 5 below.

TABLE 5: WATER TIGHTNESS

WINDOW RATING		
FOR USE IN SMALL BUILDINGS	FOR USE IN OTHER BUILDINGS	TEST PRESSURE DIFFERENTIAL, Pa
Storm	—	0
B1	B1	150
B2	B2	200
B3	B3	250
—	B4	400
—	B5	500
—	B6	600
—	B7	700

The tests are performed in accordance with the A.S.T.M. E-547-86 specification, i.e. with a static pressure differential (see above table) across the window (including screen) and a water rate of flow rate equal to 3.,4 li/m^2-min.(5 U.S.gal./ft^2-h). At each test pressure, four cycles are completed.

Each cycle consists of five minutes with the pressure applied and one minute with the pressure released. Throughout the test, water is sprayed continuously.

3.1.5 Condensation Resistance Test

Testing procedure

The test consists of sealing the specimen in a test unit between hot and cold chambers. The specimen is mounted in a wall separating the hot and cold chambers, with the exterior side of the window facing into the cold chamber.

Requirements of CAN/CSA-A440-M90 Standard

The room-side temperature (Th) shall be maintained at 20 ± 1°C and the weather-side temperature (Tc) shall maintained at -30 ± 1°C.

The pressure difference across the specimen shall be adjusted to be near zero ± 5 Pa when measured at mid-height of the specimen.

Once steady state has been reached, maintain the specimen for five hours at test temperatures and then take five consecutive observations at 10 minute intervals. The temperature variation shall be within 1°C for the five observations at each location.

A temperature index (I) is then calculated using the noted measurements. The temperature index is calculated as follows:

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{TH - Tc} \times 100$$

For the frame

$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

		EXAMPLE
-	Average surface temperature of glass (Tg)	= -2.0 °C
-	Coldest frame temperature (Tf)	= 0.0 °C
-	Difference between the temperature (Tg) and the weather side temperature (Tc)	= 28.0 °C
-	Difference between the temperature (Tf) and the weather side temperature (Tc)	= 30.0 °C
-	Difference between the room-side temperature (Th) and the weather-side temperature (Tc)	= 50.0 °C
-	Temperature index for the glass $Ig = \frac{28}{50} \times 100$	= 56.0
-	Temperature index for the frame $If = \frac{30}{50} \times 100$	= 60.0

The minimum acceptable value of I is 40 to pass the condensation resistance test.

3.2 Pressure cycling test

The cycling air pressure system is designed to perform testing as per ASTM E 1233-88.

ASTM Standard Test E 1233-88 is designed to simulate the effects of cycling or repeated wind loads on exterior building components by applying a cycling positive/negative air pressure differential across them. Specific examples of components listed in the standard for which this test method is recommended include:

- assemblies with non-self-locking threaded fasteners;
- assemblies with fastenings or attachments prone to ratcheting action;

- welded assemblies or assemblies with notch effects;
- masonry veneers on flexible back-up systems;
- innovative metallic assemblies in which local yielding may occur at unusual connection details, and;
- new materials previously untested for cyclic conditions.

All of the examples listed above have the potential for fatigue failure under cyclic wind loading.

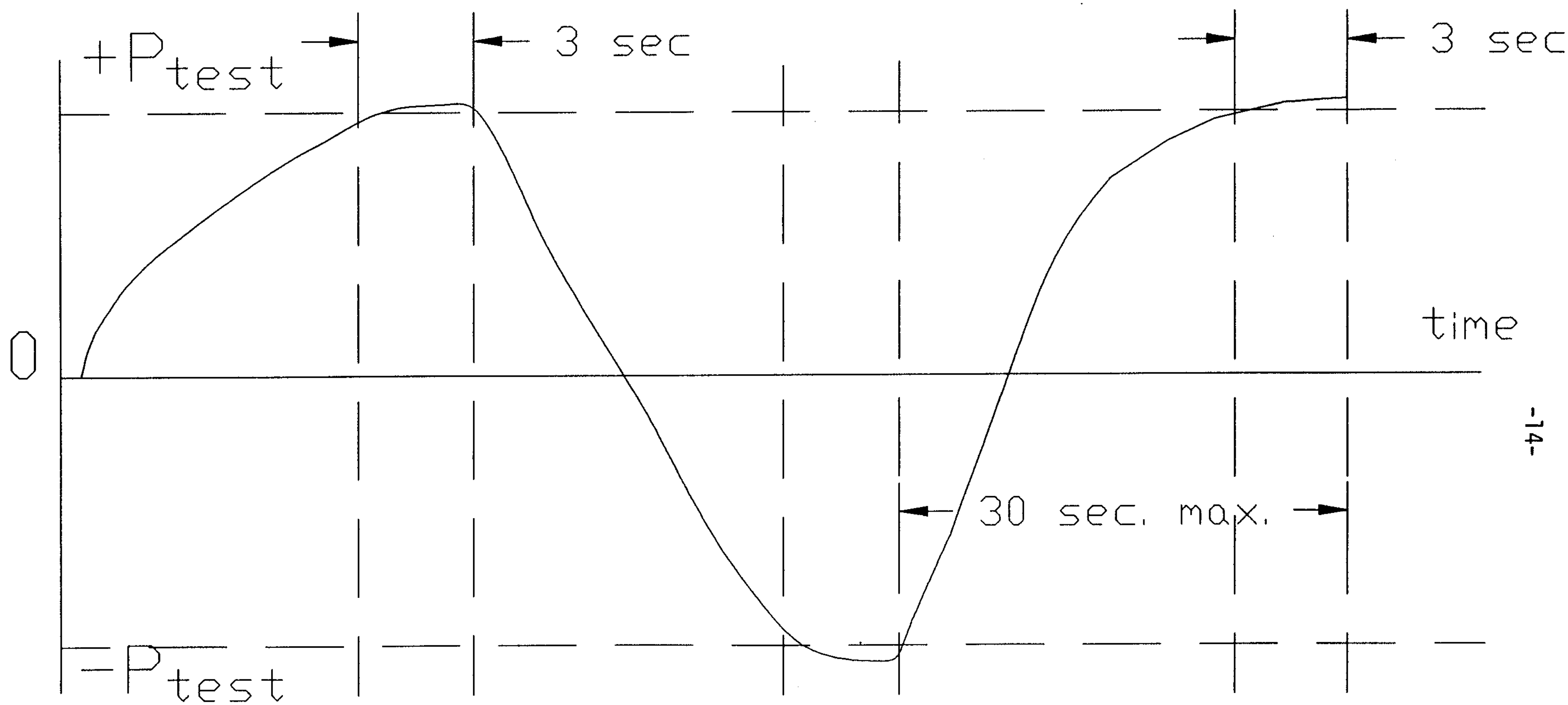
The design criteria as specified by the standard included:

- the positive and negative cyclic test loads are to be taken as 75% of the test specimen's design wind loads (approximately 0.5 to 3.0 kPa for most applications);
- the test pressure is to be measured to within a tolerance of ±2% or ±2.5 Pa, whichever is greater;
- the cyclic air pressure system should be able to perform one half cycle (apply, maintain, and release the load) in not longer than 30 s (see figure 2) to minimize the possibility of glass breakage (where applicable), and;
- the cyclic test loads are to be maintained within the given tolerances for 3 s during every half cycle (Fig. 2).

The cyclic test load was choosen as 75% of the average design wind load for windows installed at a height of 10 m above ground in nive Canadian cities. As illustrated in Table 6, 75% of the average design load is found to be 1.2 kPa (1.6 x .75).

TABLE 6: DETERMINATION OF THE TEST PRESSURE

CITY	DESIGN WIND LOAD (kPa)
Vancouver	1.69
Calgary	1.50
Regina	1.31
Winnipeg	1.31
Toronto	1.50
Quebec	1.50
Saint John	1.50
Charlottown	1.87
St-John's	2.25
Average design wind load	1.60



TEST CHAMBER PRESSURE CYCLING

FIGURE 2

4. RESULTS

Tables 7, 8, 9 and 10 give the intermediate and final results applicable to each performance criteria.

4.1 EASE OF OPERATION

This test was performed initially and after 500, 1000 and 2000 cycles on all operating windows.

Table 7 gives the initial and final (2000 cycles) operating force. Intermediate results at 500 and 1000 cycles were removed since the magnitude of the forces measured were approximately equal to forces indicated at 2000 cycles.

4.2 AIR LEAKAGE

Table 8 gives the measured air leakage rate per unit length of crack upon completion of each interval of pressure cycling. The equivalent A440 rating is also shown adjacent to the measured value (see Table 4).

4.3 RESISTANCE TO WATER PENETRATION

Table 9 shows the equivalent A440 rating obtained on each window upon completion of the predetermined number of cycles.

In order to obtain the minimum performance level B1 of the A440 standard, improvements had to be performed on some of the original windows. These improvements are listed below for each product of concern:

PC-1: Seal right and left corners at sill versus jambs junctions.

PC-11: Seal the bottom right corner at sill versus jamb.

PC-15: Seal right and left corners at sill versus jambs junctions.

PC-17: Seal around the casing of the roto-operator.

PC-13: Seal snap-on cap at sill.

PC-8 : It was impossible to improve the performance of this product to meet the B1 level. We introduced a B 1/2 level which corresponds to a pressure difference of 75 Pa. This is made in order to obtain an initial performance level so that testing could proceed.

4.4 CONDENSATION RESISTANCE

For each product, Table 10 shows the calculated temperature index of glass and frame upon completion of the preditermined number of cycles. Surface temperature distribution and detailed calculations are given in Appendix "C".

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TABLE 7: EASE OF OPERATION

TYPE AND SPECIMEN NUMBER	INITIAL				2000 CYCLES				% VARIATION IN FORCE (%)
	STATIC N (lb)		DYNAMIC N (lb)		STATIC N (lb)		DYNAMIC N (lb)		
	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE	
CASEMENT									
PC-9 (PVC)	24.5 (5.5)	40 (9)	11.1 (2.5)	11.1 (2.5)	80.1* (18)	44.5 (10)	31.1* (7)	22.2 (5)	+ 129.6
PC-10 (PVC)	12.5 (2.8)	14.2 (3.2)	6.7 (1.5)	6.7 (1.5)	53.4 (12)	35.6 (8)	11.12 (2.5)	22.2 (5)	+ 193.8
PC-15 (WOOD)	22.2 (5)	26.7 (6)	6.7 (1.5)	13.3 (3)	35.6 (8)	26.7 (6)	8.9 (2)	13.3 (3)	+ 23.3
PC-17 (WOOD)	45.8 (10.3)	19.1 (4.3)	10.2 (2.3)	8.9 (2)	44.5 (10)	37.8 (8.5)	8.9 (2)	13.3 (3)	+ 32.9
VERTICAL SLIDER									
PC-1 (AL)	164.6 (37)	155.7 (35)	148.8* (33)	89 (20)	169 (38)	111.2 (25)	137.9* (31)	75.6 (17)	- 11.8
PC-11 (PVC)	160 (36)	151.2 (34)	106.8* (24)	102.3* (23)	177.9 (40)	160.1 (36)	106.8* (24)	106.8* (24)	+ 36.2
PC-18 (WOOD)	131.2 (29.5)	111.2 (25)	124.6* (28)	64.5 (14.5)	106.8 (24)	160.1 (36)	164.6* (37)	146.79* (33)	+ 46.3
HORIZONTAL SLIDER									
PC-8 (PVC)	35.6 (8)	48.9 (11)	44.5 (10)	62.3* (14)	62.3* (14)	66.7 (15)	53.4* (12)	57.8* (13)	+ 31.0

* Exceeds the maximum allowable force specified by the A440 Standard.

TABLE 8: AIR LEAKAGE

TYPE AND SPECIMEN	INITIAL $m^3/h\text{-}m$ (SCFM/ft)	500 CYCLES $m^3/h\text{-}m$ (SCFM/ft)	1000 CYCLES $m^3/h\text{-}m$ (SCFM/ft)	2000 CYCLES $m^3/h\text{-}m$ (SCFM/ft)	δQ	
					ABSOLUTE $m^3/h\text{-}m$ (SCFM/ft)	%
CASEMENT						
PC-9 (PVC)	0.424-A3 (0.076)	0.663-A2 (0.119)	0.735-A2 (0.132)	1.541-A2 (0.2766)	1.117 (0.201)	+ 263
PC-10 (PVC)	1.042-A2 (0.187)	1.174-A2 (0.211)	1.087-A2 (0.195)	1.126-A2 (0.202)	0.084 (0.015)	+ 8.1
PC-15 (WOOD)	0.279-A3 (0.050)	0.312-A3 (0.056)	0.303-A3 (0.054)	0.55-A3 (0.099)	0.271 (0.049)	+ 97.1
PC-17 (WOOD)	0.518-A3 (0.093)	0.531-A3 (0.095)	0.531-A3 (0.095)	0.640-A2 (0.115)	0.122 (0.022)	+ 23.6
VERTICAL SLIDER						
PC-1 (AL)	1.020-A2 (0.183)	1.143-A2 (0.205)	1.07-A2 (0.192)	1.443-A2 (0.259)	0.423 (0.076)	+ 41.5
PC-11 (PVC)	1.95-A1 (0.35)	6.814* (1.223)	7.061* (1.267)	7.323* (1.314)	5.373 (0.964)	+ 275.4
PC-18 (WOOD)	0.736-A2 (0.132)	0.978-A2 (0.175)	0.943-A2 (0.169)	0.920-A2 (0.165)	0.184 (0.033)	+ 25
HORIZONTAL SLIDER						
PC-8 (PVC)	2.563-A1 (0.460)	2.570-A1 (0.461)	2.600-A1 (0.467)	2.814* (0.505)	0.251 (0.045)	+ 9.8
FIXED						
PC-13 (PVC)	0.141-FIXED (0.0253)	0.162-FIXED (0.0290)	0.173-FIXED (0.031)	0.173-FIXED (0.031)	0.032 (0.0057)	+ 2.27
PC-16 (WOOD)	0.0167-FIXED (0.003)	0.0167-FIXED (0.003)	0.020-FIXED (0.0036)	0.0232-FIXED (0.0042)	0.0065 (0.0012)	+ 39

* Exceeds the maximum allowable air leakage specified by the A440 Standard.

TABLE 9: RESISTANCE TO WATER PENETRATION

TYPE AND SPECIMEN NUMBER	INITIAL	1000 CYCLES	2000 CYCLES
CASEMENT			
PC-9 (PVC)	B3	B3	B3
PC-10 (PVC)	B2	B2	B2
PC-15 (WOOD)	B2	B2	B2
PC-17 (WOOD)	B3	B3	B3
VERTICAL SLIDER			
PC-1 (AL)	B1	B1	B1
PC-11 (PVC)	B2	B1	B 1/2* (75 Pa)
PC-18 (WOOD)	B7	B6	B6
HORIZONTAL SLIDER			
PC-8 (PVC)	B 1/2* (75 Pa)	B 1/2* (75 Pa)	B 1/2* (75 Pa)
FIXED			
PC-13 (PVC)	B3	B3	B3
PC-16 (WOOD)	B7	B7	B6

* Lower than the minimum acceptable level of A440.

TABLE 10: TEMPERATURE INDEX (CONDENSATION RESISTANCE)

TYPE AND SPECIMEN NUMBER	INITIAL		2000 CYCLES	
	TI_G	TI_F	TI_G	TI_F
CASEMENT				
PC-9 (PVC)	60	52	54	22*
PC-10 (PVC)	60	18*	54	16*
PC-15 (WOOD)	58	48	54	52
PC-17 (WOOD)	60	38*	58	40
VERTICAL SLIDER				
PC-1 (AL)	62	50	60	40
PC-11 (PVC)	60	10*	56	12*
PC-18 (WOOD)	60	32*	58	34*
HORIZONTAL SLIDER				
PC-8 (PVC)	60	40	58	40
FIXED				
PC-13 (PVC)	58	58	58	56
PC-16 (WOOD)	56	58	60	58

* TI lower than minimum acceptable value specified by A440 (TI = 40)

TI_G: Glass temperature index

TI_F: Frame temperature index

5. OBSERVATIONS AND DATA ANALYSIS

5.1 EASE OF OPERATION

A) CASEMENT WINDOWS

Except for PVC windows (PC-9 and PC-10), all wood windows showed an acceptable increase in the force required to operate the mechanism.

We expect that the increase in the force required to operate PVC windows (130% and 194%) is caused by the fact the sash members were not reinforced, and as such, PVC members were subjected to large deflections during the pressure cycling test. These large deflections may have changed something in the operating mechanism. One should notice that specimen PC-9 does not meet the ease of operation minimum requirement of the A440 standard.

B) VERTICAL SLIDING WINDOWS

The change in ease of operation varies from -11.8 to + 46.3%.

One should notice that for all of the supplied specimens, the force required to maintain motion (before and after pressure cycling) exceeds the maximum allowable force specified by the A440 standard.

C) HORIZONTAL SLIDING WINDOW

The change in ease of operation was found to be + 31%.

Here again, the force required to maintain motion (before and after pressure cycling) exceeds the maximum allowable force specified by the A440 standard.

5.2 AIR LEAKAGE

After the pressure cycling test, all windows showed an increase in the air leakage rate. The magnitude of the variation goes from + 8% to 275%.

The two largest increase in air leakage rates were recorded on PVC windows (PC-9 and PC-11). Such increase could be mainly caused by the low rigidity of PVC sash members (non-reinforced), possible compression set of weatherstripping and possible permanent deformation of sash members after the pressure cycling test.

The next larger increase air leakage rate (+97%) occured through specimen PC-15 (wood-casement). Such air leakage increase is probably caused by compression set of weatherstrips.

The increase in air leakage rate through all the other specimen is probably caused by compression set of weatherstrips.

5.3 RESISTANCE TO WATER PENETRATION

5.3.1 CASEMENT WINDOWS

Upon completion of the pressure cycling test, all casement windows kept their original level of performance.

5.3.2 VERTICAL SLIDING WINDOWS

Upon completion of the pressure cycling test:

- the aluminum window kept the original level of performance
- PC-11 and PC-18 specimens lowered their performance by at least one level, i.e. PC-11 went from B2 to B 1/2, while PC-18 went from B7 to B6.

5.3.3 HORIZONTAL SLIDING AND FIXED WINDOWS

All specimens kept their original level of performance after completion of the pressure cycling test.

5.4 CONDENSATION RESISTANCE

5.4.1 GLASS TEMPERATURE INDEX (TI_G)

After the pressure cycling test, the glass temperature index of all specimens remained nearly identical to the initial value.

5.4.2 FRAME TEMPERATURE INDEX (TI_F)

The largest decrease (δ = 30 points) in the performance of a window with respect to condensation resistance occured on specimen PC-9. Photograph no. 1 and 2 show what happened during the final test, i.e. the bowing effect of the stile on the lock side of the sash, when the specimen is subjected to a temperature differential of 50°C. Taking into account the possible effect of weatherstrip compression set, the creeping of PVC during the pressure cycling test and the bowing effect of sash members, all these phenomenon may create a crack through which cold air will flow through to lower sash and frame temperatures.

Photographs no. 3 shows that eventhough the sash members of this window (PC-11, vertical slider) are made of an insulating material (PVC), the differential movement between sash and frame may also create a crack through which cold air will flow, thereby creating cold spots on the interior side of the building. This is probably why the above window does not meet the minimum temperature index of 40 specified by the A440 standard.

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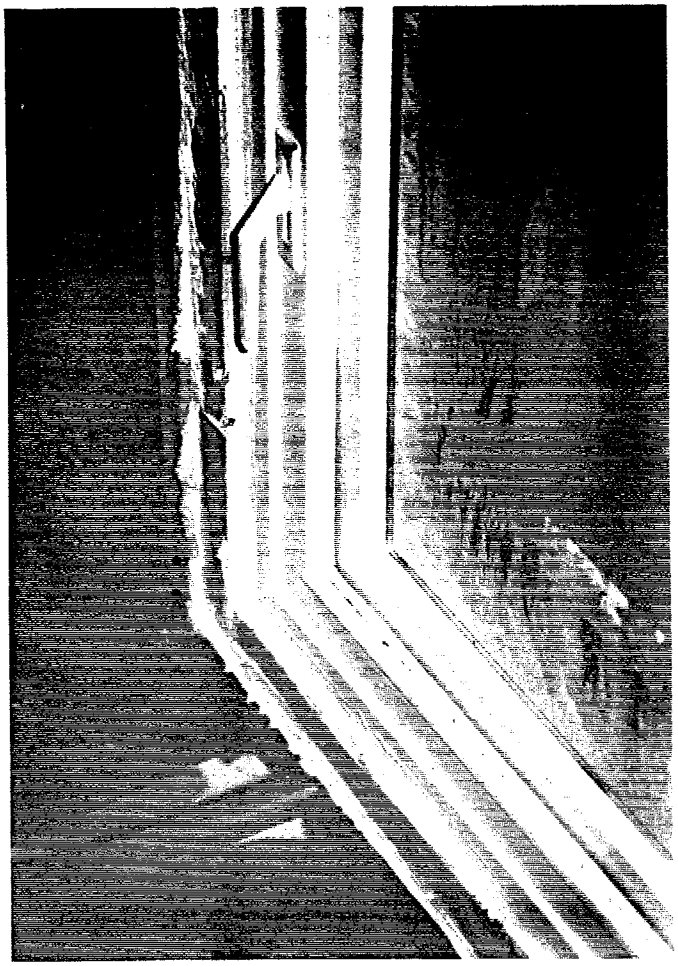
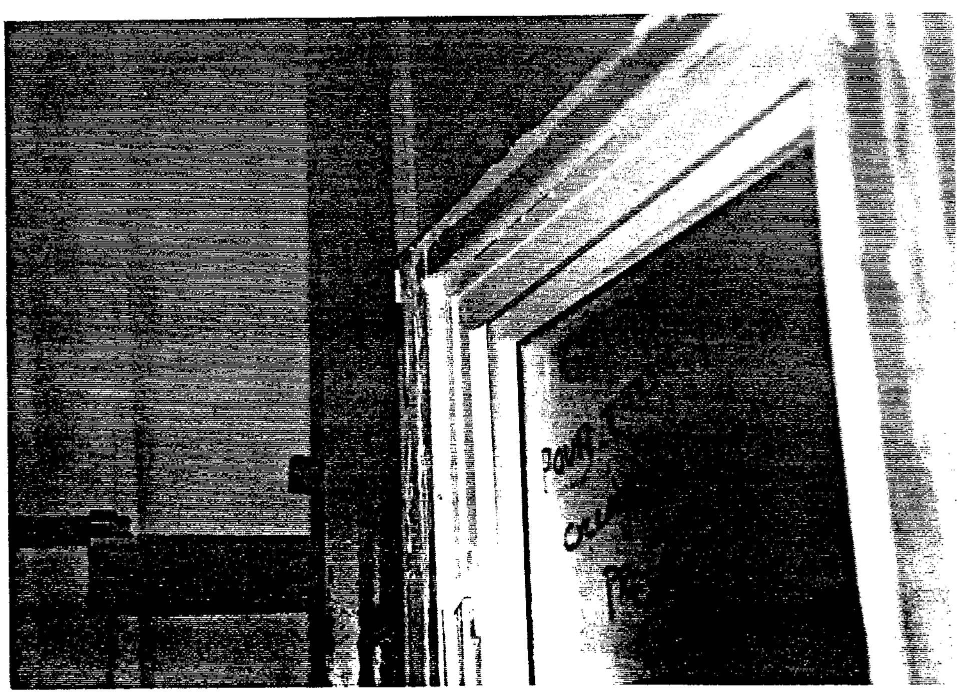
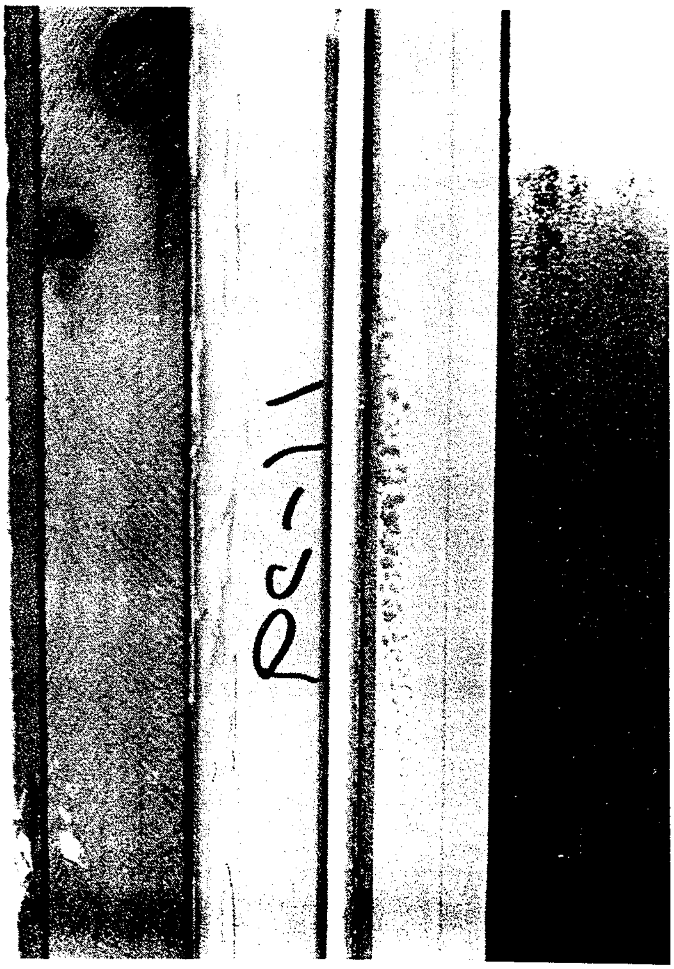


Photograph no.: 1
PC-9 - Bottom left hand corner - Lock side



Photograph no. 2: PC-9 - Top left corner - Lock side

Also, the minimum temperature index was not met initially and after pressure cycling by specimens no. PC-10 (PVC), PC-17 (WOOD) and PC-18 (WOOD). This is certainly caused by a cold air flow through a crack between sash and frame.



Photograph no.3 : PC-11 - Cold air leakage between sash and frame members

Both fixed windows did not suffer any change in performance with respect to condensation resistance after the pressure cycling test.

6. "OFFICIAL" VERSUS "TESTED" RATINGS

All specimens tested were supplied by different manufacturers as new windows. Most of these windows were previously tested by different laboratories in accordance with the CAN/CSA-A440-M90 Standard. Table 11 shows the differences between the "official" rating specified by CCMC versus the initial and final ratings of the windows that were tested during this project.

TABLE 11: "OFFICIAL" VERSUS "TESTED" RATINGS

TYPE AND SPECIMEN NUMBER	OFFICIAL	TESTED	
		INITIAL	FINAL (2000 CYCLES)
CASEMENT			
PC-9 (PVC)	A3 B3	A3 B3	A2 B3
PC-10 (PVC)	A3 B3	A2 B2	A2 B2
PC-15 (WOOD)	A3 B3	A3 B2*	A3 B2
PC-17 (WOOD)	A3 B3	A3 B3*	A2 B3
VERTICAL SLIDER			
PC-1 (AL)	A2 B3	A2 B1*	A2 B1
PC-11 (PVC)	N/A N/A	A1 B2	5.37 B 1/2
PC-18 (WOOD)	A3 B3	A2 B7	A2 B6
HORIZONTAL SLIDER			
PC-8 (PVC)	A2 B2	A1 B 1/2	2.81 B 1/2
FIXED			
PC-13 (PVC)	N/A N/A	FIXED B3	FIXED B3
PC-16 (WOOD)	N/A N/A	FIXED B7	FIXED B6

* These windows were improved prior to start of the pressure cycling test.

7. CONCLUSIONS

7.1 EASE OF OPERATION

Table 7 shows that except for the aluminum sliding window (PC-11), the operating force required to initiate and/or maintain motion of sashes after the pressure cycling test were all higher than the initial force (s). The force increase ranged from 23% to 194%.

The highest increase in the operating forces were recorded on two PVC casement windows (PC-9 and PC-10).

7.2 AIR LEAKAGE

Table 8 shows that upon completion of pressure cycling, all specimens showed an increase in the air leakage rate ranging from 8% to 275%.

The largest increase were recorded on two PVC windows (PC-9 and PC-11). Most of the air leakage increase seems to be caused by a combination of the following factors: compression set of weatherstripping, creeping or permanent deformation of PVC sash members during pressure cycling and the possible lack of rigidity of the sash members.

7.3 RESISTANCE TO WATER PENETRATION

Table 9 shows that upon completion of pressure cycling, the resistance to water penetration of most specimens did not change from their respective initial value.

Only three windows (PC-11, PC-18 and PC-16) suffered a decrease in rating. PC-18 and PC-16 lowered their performance by one level, while PC-11 did not meet the minimum performance level B1 after pressure cycling.

7.4 CONDENSATION RESISTANCE (TEMPERATURE INDEX)

Even though the condensation resistance test is not mandatory for PVC and wood windows (A440), the testing showed that even if the framing material is a poor heat conductor or a good insulator (PC-10, PC-17, PC-11 and PC-18), the interior frame surface temperatures can be lower than the minimum acceptable (level (TI = 40). Such low surface temperatures can only be attributed to cracks that may develop between sash and frame members when subjecting the windows to a large temperature differential.

Upon completion of the pressure cycling test, the glass temperature index (TI_G) of all specimens remained nearly identical to the initial value. Nevertheless, the same pressure cycling test introduced on some windows a large decrease (δ = 30 points) of the frame temperature index (TI_F). Here again, such a decrease in performance level can only be attributed to cracks that may develop between sash and frame members.

8. RECOMMANDATIONS

- The pressure cycling test showed that in most cases there was a decrease in one or several of the performance criterion covered by the A440 Standard. To ensure durability of new windows, this new criteria of pressure cycling with the test procedure should be incorporated into the main boby of the Canadian standard.
- The condensation resistance tests conducted on non-metallic windows (wood and PVC) showed that some of these new products did not meet the minimum performance level specified by the A440 Standard. Therefore, in order to make it fair for all framing materials, the evaluation of this criteria should be made mandatory for all materials.
- To improve the certainty of the performance levels given by the CCMC accreditation, manufacturers should make random inspection during the manufacturing process and an independant certification system should be put in place.

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APPENDIX "A"

IDENTIFICATION: PC-1

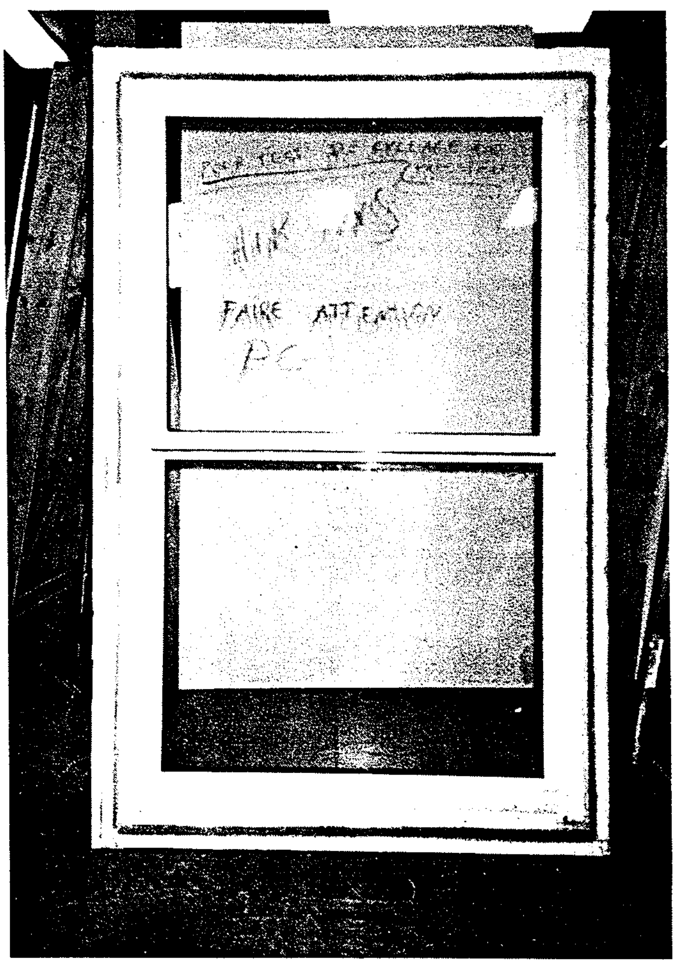
TYPE OF WINDOW: VERTICAL SLIDER

FRAME AND SASH MATERIAL: ALUMINUM

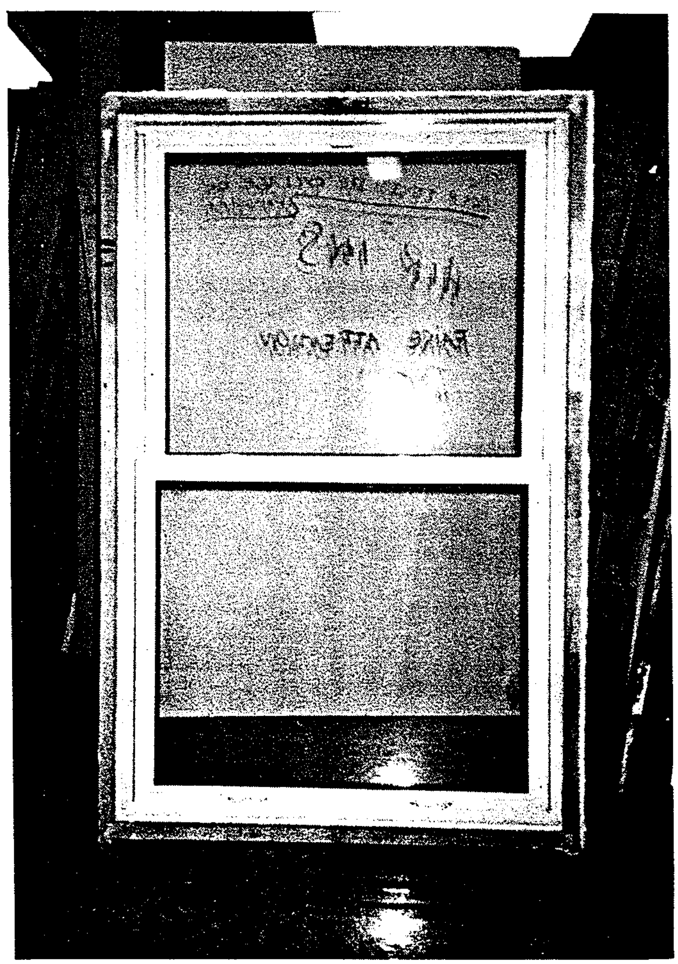
SASH'S DIMENSION: 36.125" X 60.5"

CRACK'S LENGTH: 19.1'

WEATHERSTRIPPING:
- INTERIOR: Pile type weatherstrip with low height polypropylene fin
- EXTERIOR: Pile type weatherstrip with low height polypropylene fin
- OTHER: Meeting rails: Pile type weatherstrip with high polypropylene fin



Photograph no. 4



Photograph no. 5

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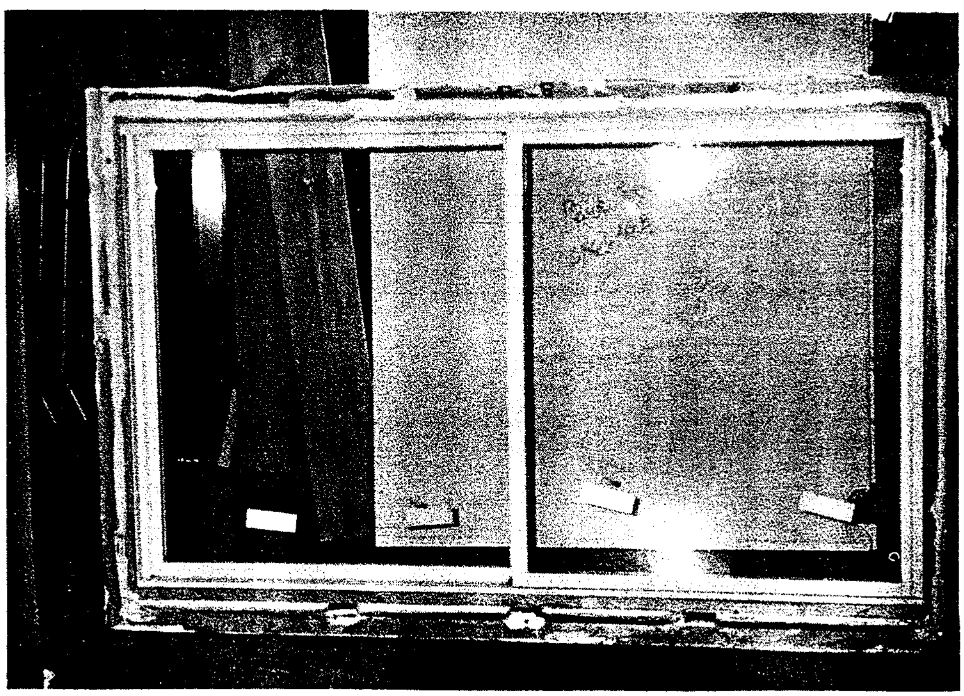
A-2

IDENTIFICATION:	PC-8
TYPE OF WINDOW:	HORIZONTAL SLIDER
FRAME AND SASH MATERIAL:	PVC
SASH'S DIMENSION:	60.75" X 35.375"
CRACK'S LENGTH:	18.97'
WEATHERSTRIPPING	OTHER: Head and base of sash: Hi-fin
	MEETING RAIL: Pile type weatherstripping
	JAMB: PVC bulb



Photograph no.6

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A-3

<u>IDENTIFICATION</u>: PC-9

<u>TYPE OF WINDOW</u>: CASEMENT

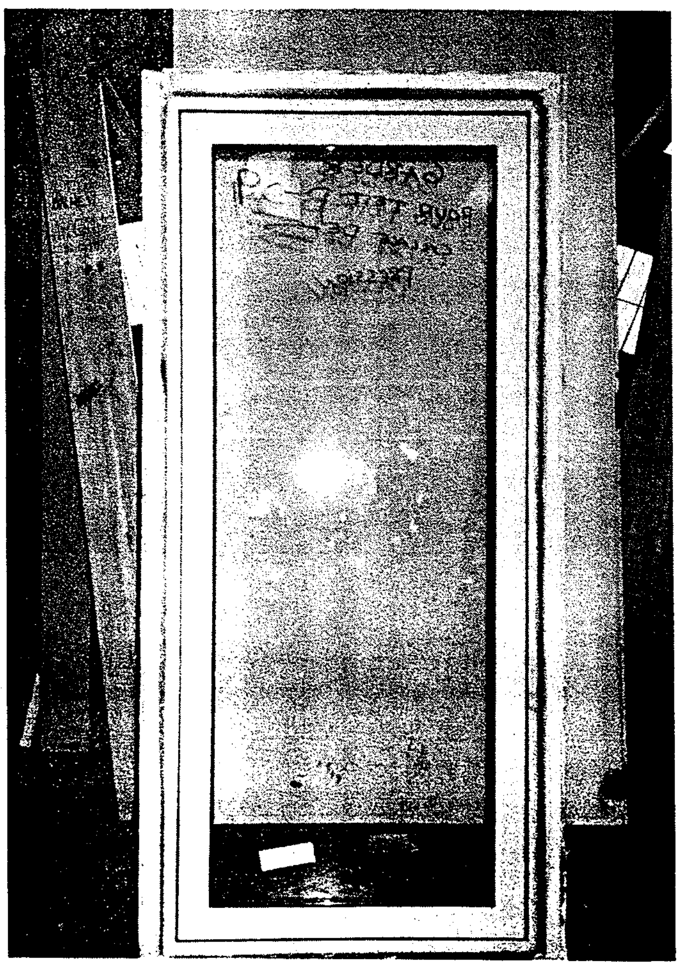
<u>FRAME AND SASH MATERIAL</u>: PVC

<u>SASH'S DIMENSION</u>: 23.375" X 68.5"

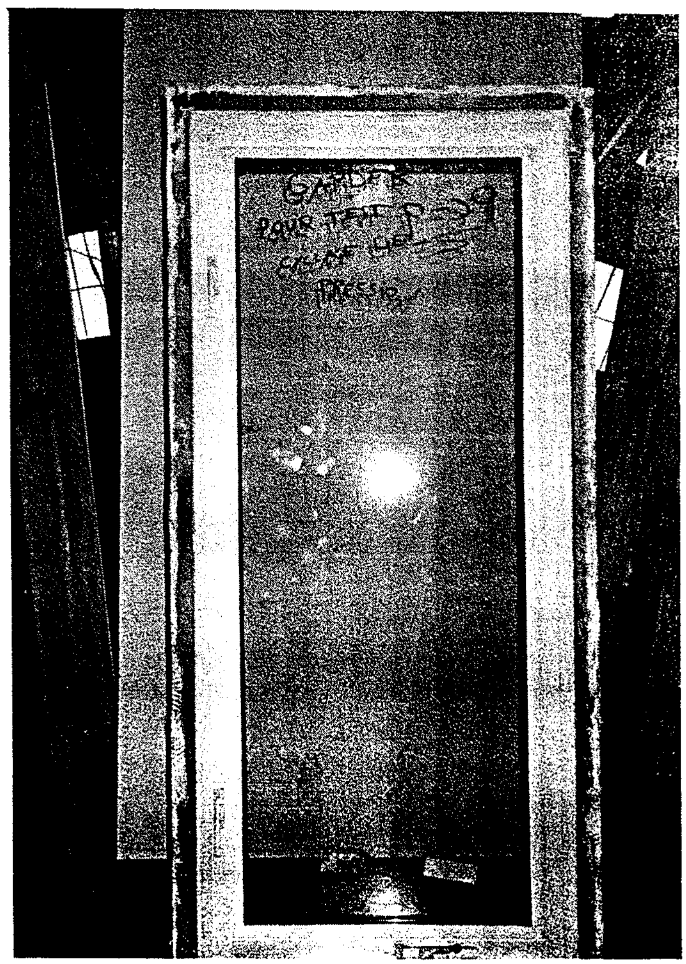
<u>CRACK'S LENGTH</u>: 15.31'

<u>WEATHERSTRIPPING</u>: INTERIOR: PVC bulb
EXTERIOR: PVC gasket

<u>NOTE</u>: No metal reinforcement.



Photograph no. 7



Photograph no. 8

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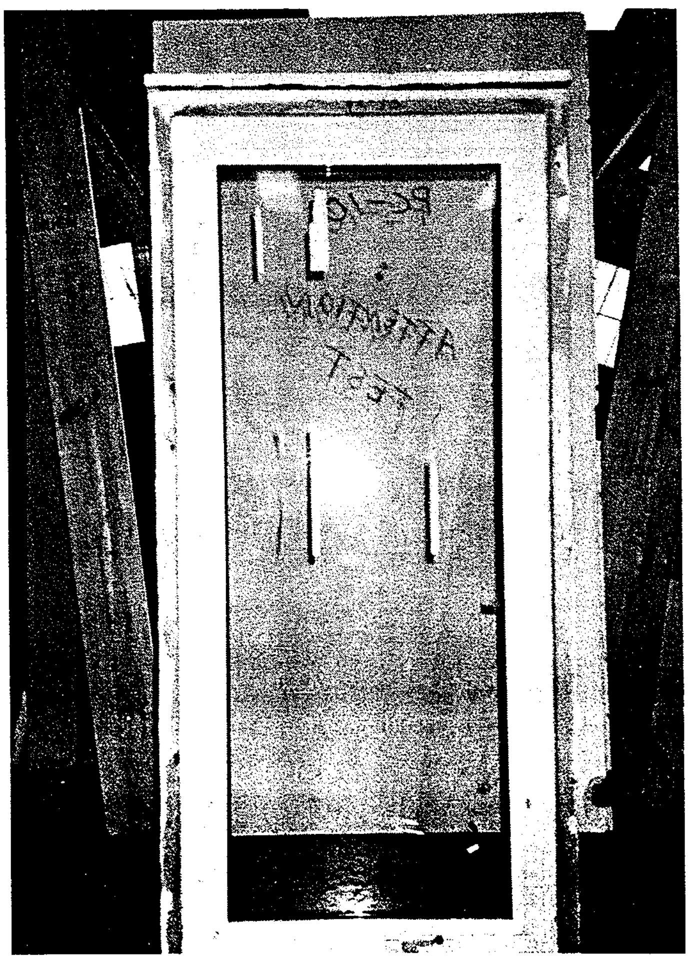
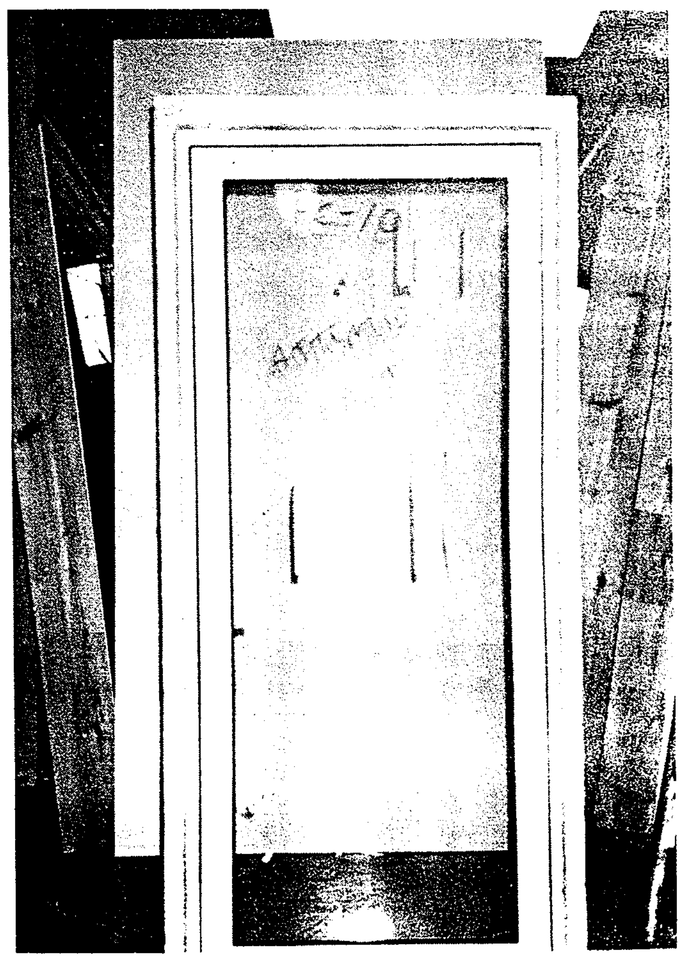
IDENTIFICATION:	PC-10
TYPE OF WINDOW:	CASEMENT
FRAME AND SASH MATERIAL:	PVC
SASH'S DIMENSION:	22.75" X 58.125"
CRACK'S LENGTH:	13.48'
WEATHERSTRIPPING:	INTERIOR: PCV bulb
	EXTERIOR: PVC gasket

NOTE: No metal reinforcement.



Photograph no. 9



Photograph no. 10

IDENTIFICATION: PC-11

TYPE OF WINDOW: VERTICAL SLIDER

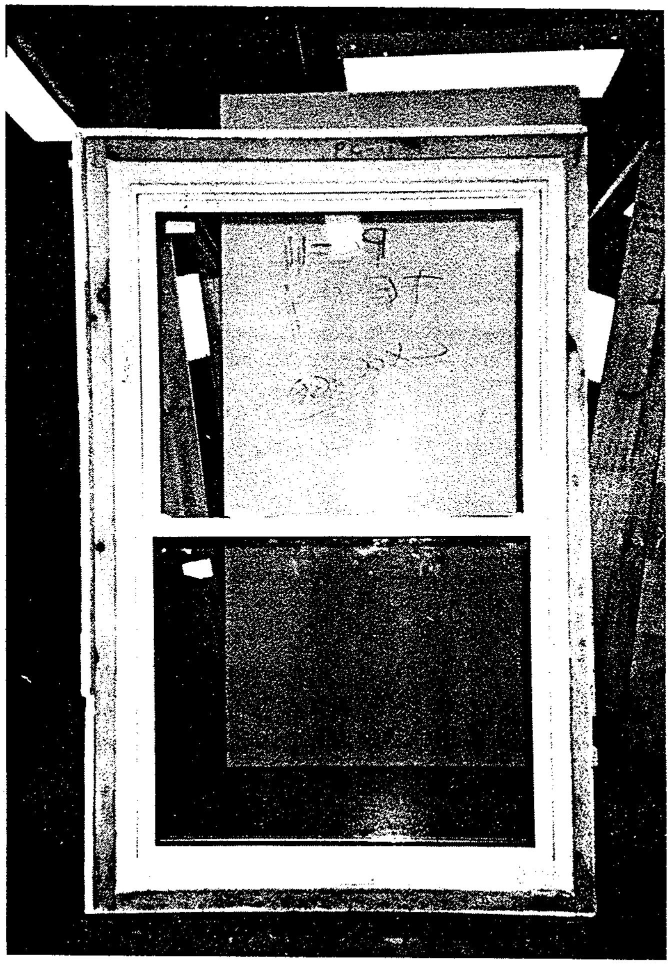
FRAME AND SASH MATERIAL: PVC

SASH'S DIMENSION: 35.75" X 59.25"

CRACK'S LENGTH: 18.81'

WEATHERSTRIPPING: INTERIOR:"Hi-Fin"

EXTERIOR:"Hi-Fin"



Photograph no. 11

AIR-INS inc.

IDENTIFICATION: PC-13

TYPE OF WINDOW: FIXED

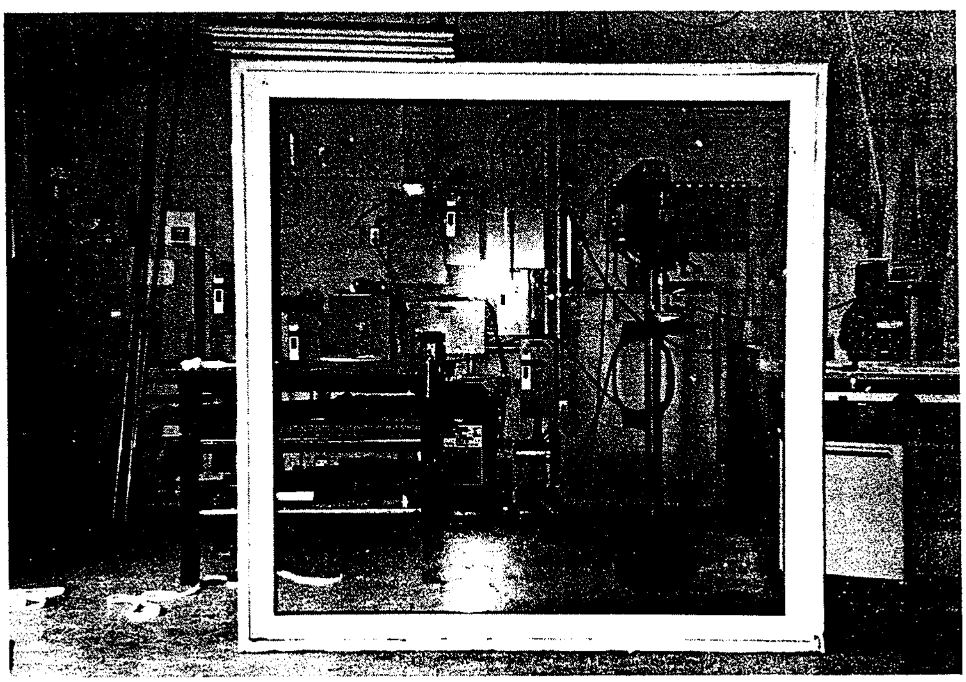
FRAME AND SASH MATERIAL: PVC

SASH'S DIMENSION: 72.5" X 72.25"

CRACK'S LENGTH: 24.125'

WEATHERSTRIPPING: INTERIOR: Continuous PVC gasket

EXTERIOR: Continuous PVC gasket



Photograph no. 12

AIR-INS inc.

A-7

<u>IDENTIFICATION</u>: PC-15

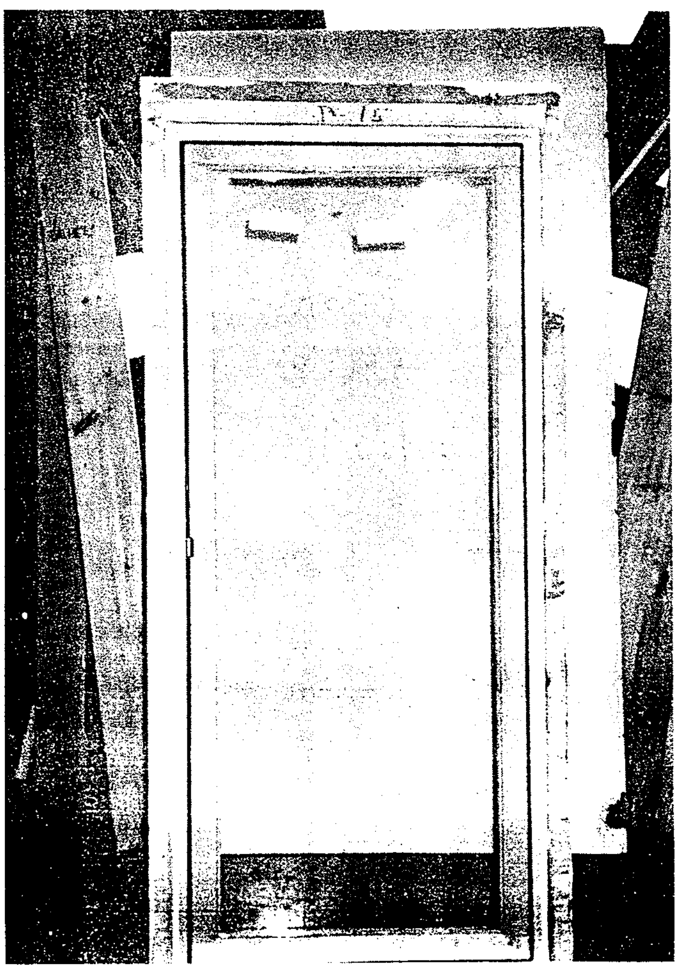
<u>TYPE OF WINDOW</u>: CASEMENT

<u>FRAME AND SASH MATERIAL</u>: WOOD

<u>SASH'S DIMENSION</u>: 25.25" X 60.75"

<u>CRACK'S LENGTH</u>: 14.33'

<u>WEATHERSTRIPPING</u>: INTERIOR: Lozaron bulb



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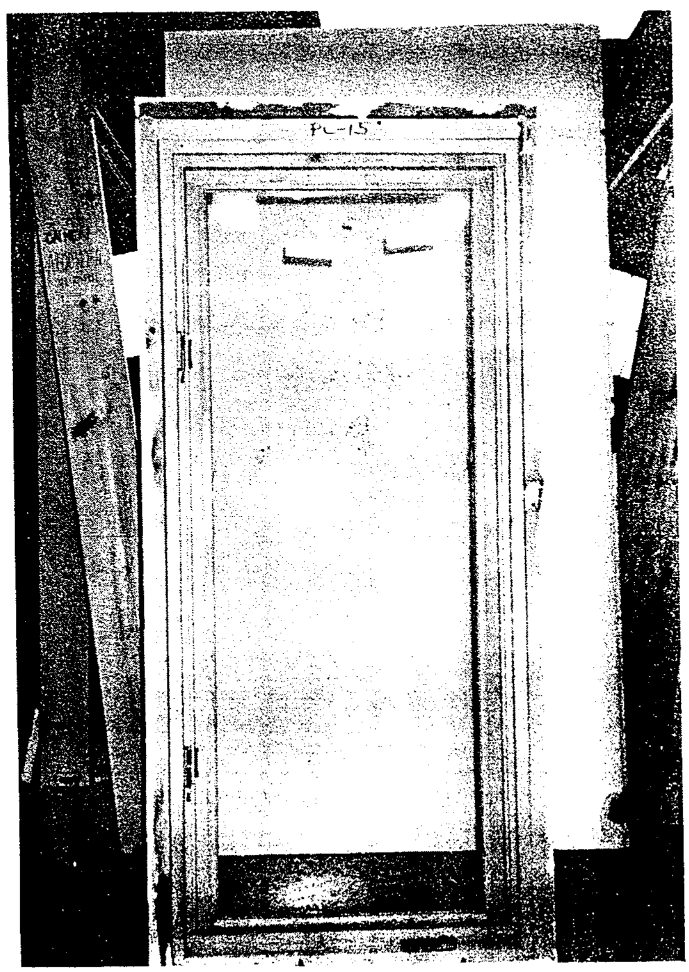


Photograph no. 14

AIR-INS inc.

IDENTIFICATION: PC-16

TYPE OF WINDOW: FIXED

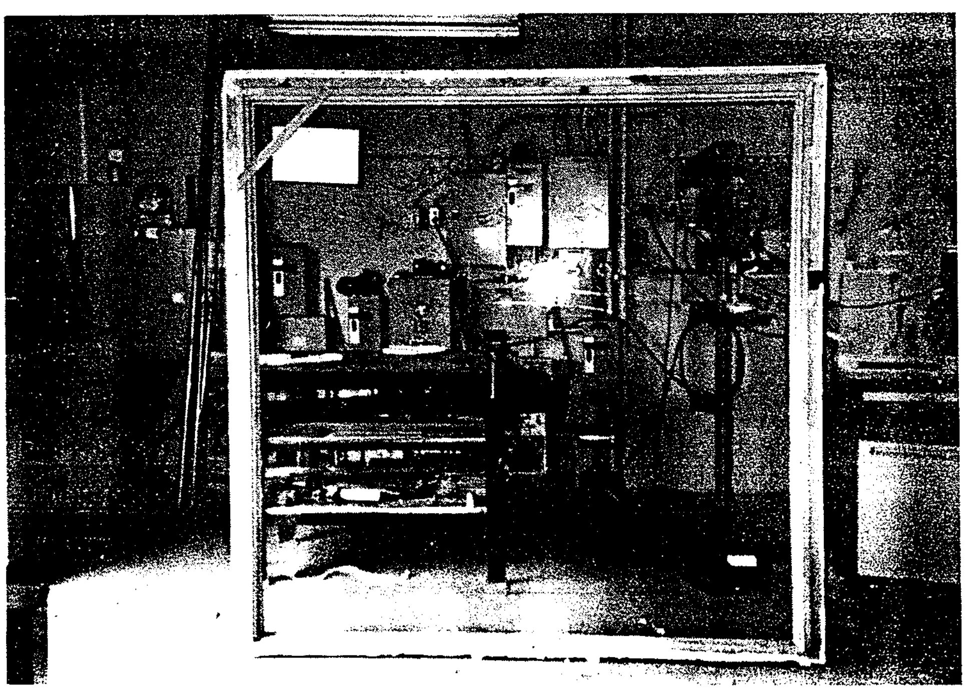
FRAME AND SASH MATERIAL: WOOD

SASH'S DIMENSION: 76.625" X 76.625"

CRACK'S LENGTH: 25.54'

WEATHERSTRIPPING: INTERIOR: Sealant

EXTERIOR: Sealant



Photograph no. 15

AIR-INS inc.

IDENTIFICATION: PC-17

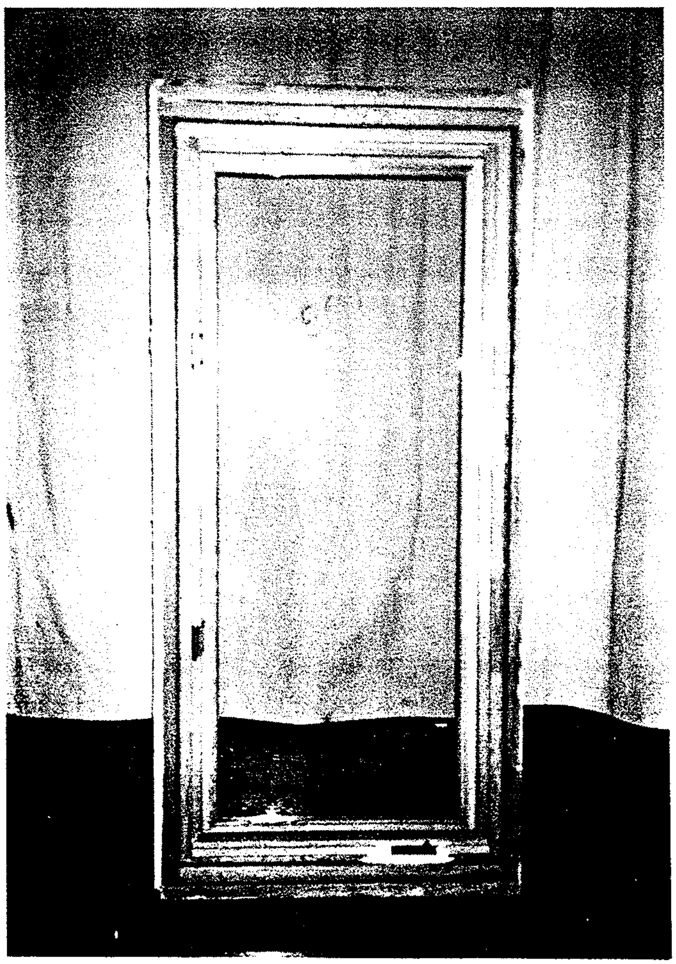
TYPE OF WINDOW: CASEMENT

FRAME AND SASH MATERIAL: WOOD

SASH'S DIMENSION: 23.75" X 58.125"

CRACK'S LENGTH: 16.65'

WEATHERSTRIPPING: INTERIOR: Lozaron bulb



Photograph no. 16

<u>IDENTIFICATION</u>: PC-18

<u>TYPE OF WINDOW</u>: VERTICAL SLIDER

<u>FRAME AND SASH MATERIAL</u>: WOOD

<u>SASH'S DIMENSION</u>: 36" X 59.5"

<u>CRACK'S LENGTH</u>: 18.92'

<u>WEATHERSTRIPPING</u>: INTERIOR: Head: Fin-seal

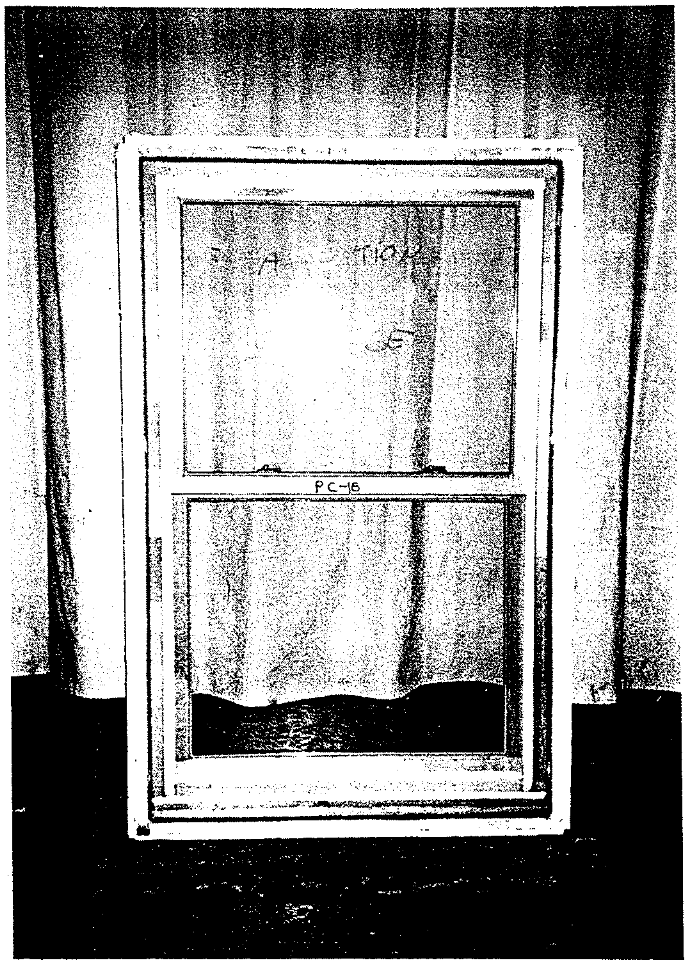
EXTERIOR: Head: Lozaron bulb

OTHER: Meeting rails: PVC gasket

JAMB: Q-Lon Bulb

SILL: INT: "Hi-fin"

EXT: on the sash: polyflex seal



Photograph no. 17

APPENDIX B

1.1 PRESSURE LOSS

Two assumptions were made in calculating pressure losses though the cycling system in order to simplify calculations. Firstly, due to the small pressures involved in the testing of windows, curtain walls, and doors, the air flow in the cycling pressure system was assumed to be incompressible. Secondly, although the flow through the system was known to vary during the cycling process, it could be considered steady at any one given point in time.

1.1.1 Pipe Friction Loss

For steady incompressible flow in a pipe, the irreversibilities can be expressed in terms of a head loss in units of length by the DarcyWeisback equation:

$$h_f = f \frac{L}{D} \frac{V^2}{2g} \qquad (1.1)$$

In this equation, h_f is the head loss, L is the pipe length of inside diameter D, V is the average flow velocity, g is the acceleration due to gravity, and f is a friction factor. This loss can be converted into units of pressure by multiplying it by the flowing fluid's specific weight.

In the transition zone, between laminar and turbulent flow, the friction factor, f, is a function of the flow's Reynolds number and the pipe's relative roughness. There are various empirical methods of obtaining f; the Hazen-Williams formula was used in this project in the form

$$f = \frac{1304.56}{C^{1.852}} V^{0.0184} R^{-0.1664} \qquad (1.2)$$

where R is the Reynolds number and C is the Hazen-Williams coefficient.

1.1.2 Minor Losses

Minor losses are those losses which occur due to the presence of various fittings in the pipe-line such as elbows, tees, valves, expansions, etc. They are called minor by convention rather than because they are small. The loss due to any one fitting is almost always determined experimentally and is given by the equation.

$$h = C_o \frac{V^2}{2g} \qquad (1.3)$$

Where h is the head loss in units of length and C_o is the experimentally determined loss coefficient. For this project, the values of C_o used were provided in the ASHRAE handbook.

1.2 SYSTEM OPERATING POINT

In an air flow system using a blower and connected piping, the point of operation is at a flow rate where the head produced by the flower is equal to the sum of the head losses through the piping system. Thus the operating point is where the blower characteristic curve intersects the system curve (see Figure 6 on page B-9).

The system curve is an addition of the system's static and dynamic heads at various flow rates. In the wind load testing of windows, the static head is the test chamber pressure; that is, the useful effect. The dynamic head, on the other hand, is a loss which has no useful effect. This loss occurs in the pipe-line between the blower and the test chamber and is a combination of the pipe friction losses of Section 1.1.1 and the minor losses of Section 1.1.2 and thus varies with the square of flow velocity.

1.3 CONTROL VALVES

The purpose of a control valve is to throttle the flow of fluid passing through it, This incurs a dynamic head drop in the fluid which varies with the square of flow velocity. Because control valves are adjustable in their restriction of the flow, they may be used to modify the system curve, as described in Section 1.2, by increasing or decreasing the dynamic head loss of the pipe-line. For window pressure testing applications, by modifying the pipe-line's dynamic head curve, the system operating point may be changed which in turn allows the control of the static pressure in the test chamber.

An important aspect of control valves is their gain, defined as

$$K_C = \frac{\text{change in flow}}{\text{change in opening}} \qquad (1.4)$$

where K_C is the valve gain. In Figure 4 a graph of flow versus valve opening illustrates the differences in the gain of various different types of valves. Since the dynamic pressure drop across a valve is proportional to the square of the flow through the valve, a good control valve has a slowly increasing flow versus opening for most of its travel to facilitate accurate pressure adjustments. It can be seen in Figure 4 then, that globe valves tend to provide the best gain characteristics for control and that gate valves tend to provide the worst. Ball and butterfly valves fall in between these two extremes.

It is important to note that often a control valve is part of a pipe-line in which high maximum flow rates are desired, as is the case in this project. In these instances a compromise between control capability and maximum flow must be reached. A comparison of typical rated maximum flows for four different types of valves of the same diameter is given in Figure 3. Note that the globe valve, the best control valve, has by far the lowest maximum flow.

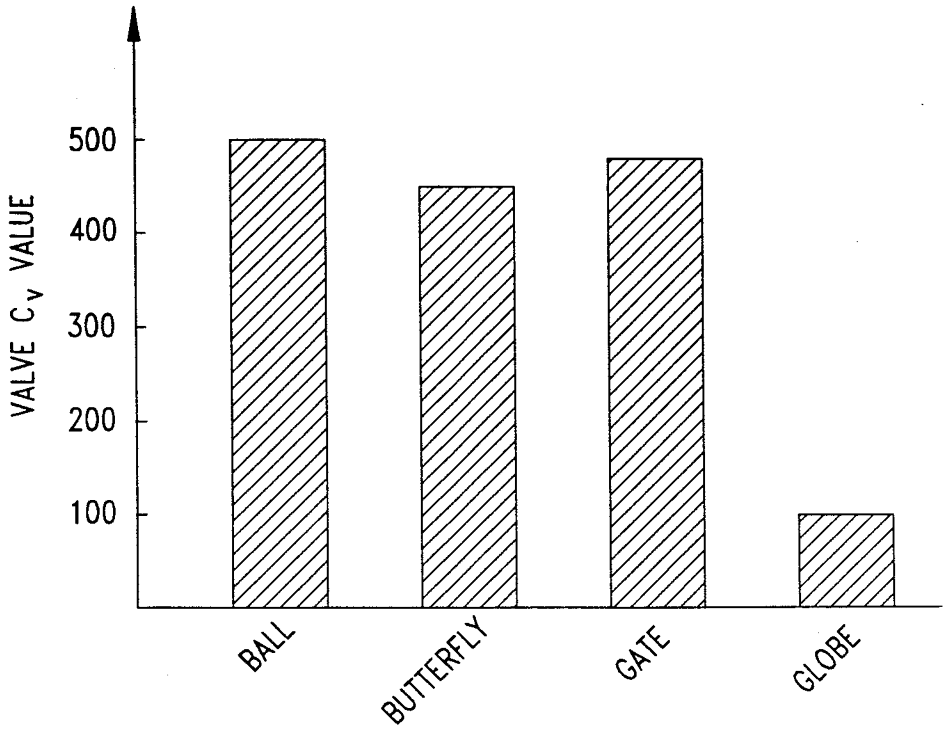


FIGURE 3. Comparison of typical rated flows for 3-inch valves.

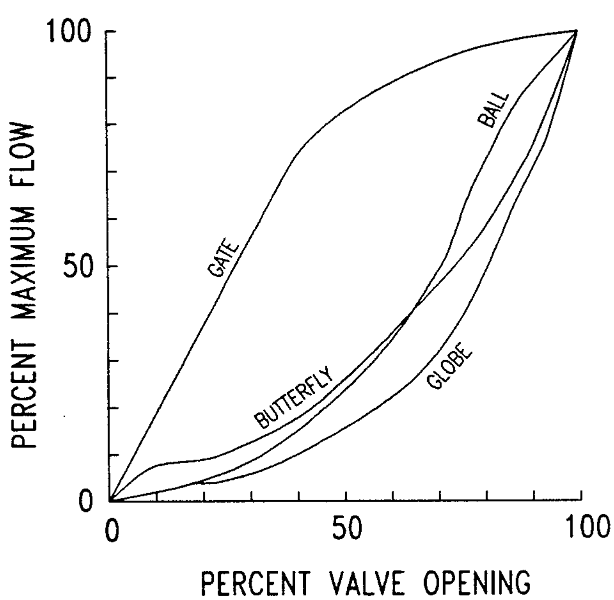


FIGURE 4. Valve flow characteristic curves.

TEST APPARATUS

2.1 PIPING

2.1.1 Pipe Type

Acrylonitrile butadiene styrene (ABS) plastic pipe was used as the basic building material of the cyclic pressure delivery device pipe-line. ABS piping was selected for several reasons, including:

- ABS pipes are very smooth, resulting in low friction losses;
- the following fluid was to be dry, low pressure air which meant that great strength or corrosion resistance was not required;
- ABS is very inexpensive as compared to other piping materials such as steel or PVC;
- ABS pipes come in many standard diameters with a large variety of fittings which are readily available;
- ABS piping systems are easy to assemble, and;
- ABS is light weight.

Also required was a flexible pipe to connect the blower to the cycling apparatus and the cycling apparatus to the test chamber. The pipe selected for this purpose was of an EVA and polyethylene construction and had a large minimum bend radius. This meant that tight-radius bends, which result in large dynamic pressure losses, would not occur in the line. The selected flexible pipe also possessed a smooth inner surface, conductive to low friction loss, and a relatively low price.

2.1.2 Pipe Diameter

Once the pipe type had been determinated, optimum pipe diameter could be calculated. The main constraint which would dictate pipe diameter was the recommendation in ASTM E 1233-88 that the time to apply, maintain (for 3 s), and release the load (one half cycle) should not be longer than 30 s to minimize the possibility of glass breakage. This meant that the system would have to be able to reach the required test chamber pressure within 13.5 s (i.e. the maximum half-cycle length of 30 s, minus the maintenance time of 3 s, all divided by 2).

By considering the air in the test chamber to be an ideal gas, the average volumetric flow rate required to obtain a given pressure in a given volume in a given amount of time can be determined using

$$Q = \frac{V \, \delta P}{\rho \, RT \, \delta t} \qquad (2.1)$$

where Q is the average volumetric flow rate, V is the test chamber volume, δP is the desired test chamber gauge pressure, R is the gas constant for air, T is the absolute air temperature, ρ is the air density, and δt is the desired amount of time to reach the test chamber pressure. Using this equation with the largest projected test chamber volume of 110 m^3, a maximum cyclic test pressure of 3.0 kPa, and a maximum allowable time of 13.5 s, a maximum average volumetric flow rate of 0.237 m^3/s was calculated. This value was subsequently used as the cyclic pressure system's design flow rate when determining the required pipe diameter.

The next step was to calculate the dynamic pressure losses through the projected pipe configuration (see Figure 5 using various different standard diameters and the two different valve types under consideration (see Section 2.1.3) for several flow rates to obtain the system curves. The pipe friction losses were found with equations (1.1) and (1.2), using estimates of the lengths of each piping system and a Hazen-Williams coefficient of 150 for ABS plastic pipe. The minor losses were calculated using equation (1.3) with loss coefficients from ASHRAE Handbook. It should be noted that the loss coefficients provided in this book are for building ducts which are neither as smooth nor as well formed as ABS fittings, thus their use incorporated a certain factor of safety in calculating the minor losses. The losses through the valves will be discussed in Section 2.1.3, these were calculated based on fully open valves and added to the other losses.

With the losses through the different diameter/valve-type combinations for several flow rates, it was possible to plot the system curves for each combination against the different blower characteristic curves to determine the operating points for each system. The design condition to be met was that the aforementioned maximum average flow rate of 0.237 m^3/s was to be achievable at half the maximum cyclic test chamber pressure of 3.0 kPa (i.e. the mean pressure) using the existing blowers. Figure 6 shows the different system curves plotted against the characteristic curve of the firm's largest blower (note that this blower was the only one capable of providing the design flow rate of 0.237 m^3/s). From this graph it can be seen that only the 4-inch systems have dynamic pressure losses low enough to operate at points sufficient to meet the design condition. Similar plots against the characteristic curves of the firm's smaller blowers indicated that the 4-inch systems were also compatible with the flows that these blowers were required to provide for their respective, smaller test chambers. As a result, a 4-inch diameter pipe-line was selected for the cyclic pressure delivery device.

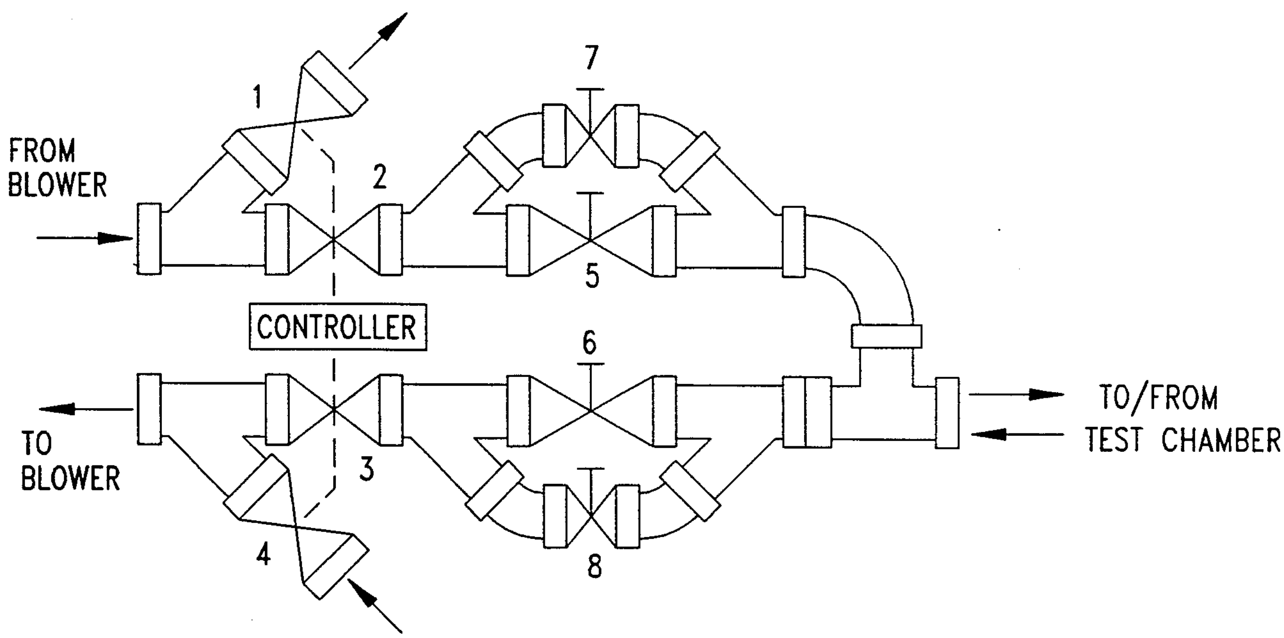


FIGURE 5 Projected pipe configuration.

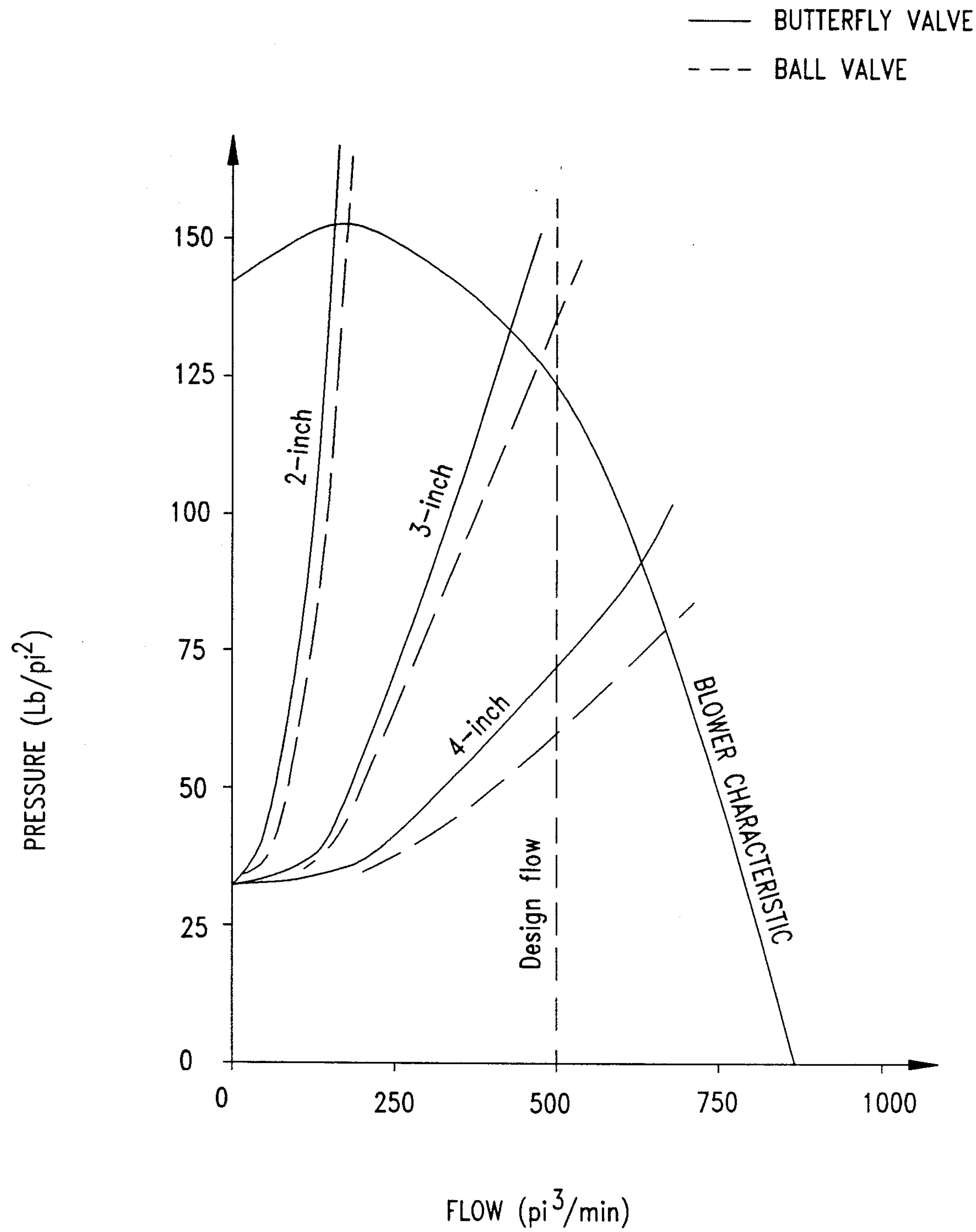


FIGURE 6. Projected characteristic curves against blower characteristic curve.

2.1.3 Valves

The valves used in the cyclic pressure delivery device serve two purposes. One is to change the direction of the air flow to the test chamber in order to supply cycling positive/negative pressure. The other is to throttle this flow in either direction in order to supply the correct magnitude of positive and negative test chamber pressure.

Initially, four different valve types were examined for their appropriateness; these were ball, butterfly, gate and globe valves.

For the flow-direction valves (1, 2, 3 and 4 in Figure 5, only the ball and butterfly valves were deemed practical for automatic actuation. This was because virtually all simple, inexpensive actuators are of the 90-degree-turn type which matches the operation of the ball and butterfly valves. On the other hand, gate and globe valves use a screw type operation tom open and close and thus require a more complex and expensive actuator. Thus ball and butterfly valves were given further consideration for automatic actuation.

The main-line throttling valves (5 and 6 in Figure 5 were not only required to provide good control characteristics but they also had to have a high maximum flow for use with the larger blower/test chamber combinations. Because of these constraints, gate valves were ruled out due to their poor control characteristics and globe valves were deemed to have inadequate maximum flow capability (see Section 1.3). Thus the ball and butterfly valves were once again selected for further consideration, this time as throttling valves, due to their combination of good control characteristics and high maximum flow capability.

At this point, the presence of secondary pipe-lines containing valves 7 and 8 in Figure 5 should be mentioned. Because a 4-inch main line had been selected and only ball and butterfly valves were under consideration for this line, the problem of accurately throttling very low flows, as would be encountered with the smallest blower test chamber combinations, appeared. This was due to the fact that both ball and butterfly valves have progressively worse throttling characteristics as they approach the extremes of their travel. In order to counter this problem, smaller secondary throttling valves were run parallel across each of the main line throttling valves. These could then used, with the main valves closed, to throttle very low flows. The installation of these secondary throttling valves had a second advantage in that they could be used in conjunction with the main throttling valves to allow for more accurate control of high flows. 3-inch globe valves were selected as the secondary throttling valves due to their excellent control characteristics over their entire range of travel.

In determining whether to use ball or butterfly valves for the main pipe-line, calculations of the dynamic pressure losses through each pipe-diameter/valve-type combination with fully open valves were made.

The loss through an open ball valve was taken to be the same as through an equal length of pipe. This method of calculating the loss can be justified in light of the fact that the ball valves under consideration were of a full-port design (i.e. they had the same diameter bore as the connected pipe with none of the contractions or expansions associated with reduced-port ball valves) and they had smooth, polished bores.

The loss through an open butterfly valve was calculated using empirical data provided by the valve manufacturer. Specifically, the manufacturer provides a rated maximum flow for each of its valves in the form of a C_V value, which is the flow of water in m^3/h through a fully open valve at a pressure drop across the valve of 133 kPa. With this data it is possible to calculate the dynamic pressure loss through an open valve at various air flow rates using the formulas provided by the manufacturer to convert from water flow to air flow. The equation used in this project was:

$$\delta P = \frac{15.9\, Q^2}{(P_2)\ (C_V^2)} \qquad (2.2)$$

where δP is the pressure drop across the valve in kPa, Q is the air flow rate in m^3/h, P_2 is the absolute valve outlet pressure in kPa, and C_V is the aforementioned rated flow supplied by the manufacturer.

With these calculated losses in hand, it was possible to compare how the two valve types would perform in the projected configuration of Figure 5. As can be seen in Figure 6, the ball valve configurations proved to have marginally less loss than those with equal diameter butterfly valves. Figure 6 also shows that the pipe's diameter has a much greater effect on the dynamic pressure loss of the system than does the type of valve used. When it was determined that a 4-inch pipe-line would be required, butterfly valves were selected over ball valves for several reasons. On reason was that, because of the ball valve,s design, with a large contact area between the ball and the seat, they require a great deal of force to operate, especially with a diameter as large as 4 inches. Butterfly valves, on the other hand, have a small contact area between the butterfly and the seat and so require much less force to operate. As a result, not only are ball valves more difficult to throttle with, but they also require a substantially more powerful and expensive actuator for automatic actuation. A second reason for choosing butterfly valves over ball valves was that large-diameter ball valves are much heavier than comparable butterfly valves and thus would add unwanted mass to the pipe-line. Thirdly, ball valves are considerably more expensive than butterfly valves in diameters over 3 inches, particularly full-port designs. Finally, the option of using a gear operator for the two main-line control valves was available for the butterfly valves but not for the ball valves (gear operators use a set of worm-and-roller gears to allow the valve to be adjusted more precisely than with the 90-degree-turn levers normally provided with ball and butterfly valves).

2.1.4 Actuators

Two types of actuators were considered for the automatic actuation of the valves controlling the direction of the air flow to the test chamber (valves 1, 2, 3 and 4 in Figure 6). Since these valves were to be essentially limited to open or shut positions, the actuators could be of the simple two-position type.

The first type of actuator considered was pneumatic. These actuators have the advantages of quick operation (less than 2 s from open to shut) and a continuous duty cycle. Their disadvantages are noisy operation and the need for a compressed air supply (preferably lubricated).

The second type of actuator considered was electric. These actuators have the advantages of quiet operation and ease of use in that they require only readily available electricity. Their disadvantages, when compared to pneumatic actuators of a similar price, are slow operation (greater than 2 s from open to shut) and a limited duty cycle (they must be allowed to cool for a certain period of time between actuations).

Because the most important factor in actuator selection was high speed (remembering that the pressure cycling was time-limited to 30 s per half-cycle) and that a compressed air source was available, pneumatic actuators were chosen to operate the flow-direction valves.

It should be noted that for the two valves connecting the blower to the atmosphere (valves 1 and 4 in Figure 5), a means of allowing them to stay partially open during their respective "shut" half-cycles was provided using extended actuator travel stops. These stops screw into either end of the actuator piston, thus allowing an adjustment of the stopping position of the piston which in turn can be used to prevent the valve from completely opening or closing.

2.2 SYSTEM CONTROL

Various components were required to control the pressure cycling process since it was to be fully automatic, including shut-down upon a major failure of the test specimen.

Figure 7 shows a schematic diagram of the control system.

2..1.1 Pressure Transducer

A pressure transducer was selected to provide a voltage proportional to the test chamber gauge pressure. The pressure transducer output is not used to set the cyclic test pressures, instead these are set using an accurate manometer during the initialization process. The pressure transducer output is used only to inform the control system when the correct test pressure is reached. Note that since the pressure transducer is not required for pressure readings but only to provide a certain voltage at a certain pressure level, its repeatability is much more important than its accuracy.

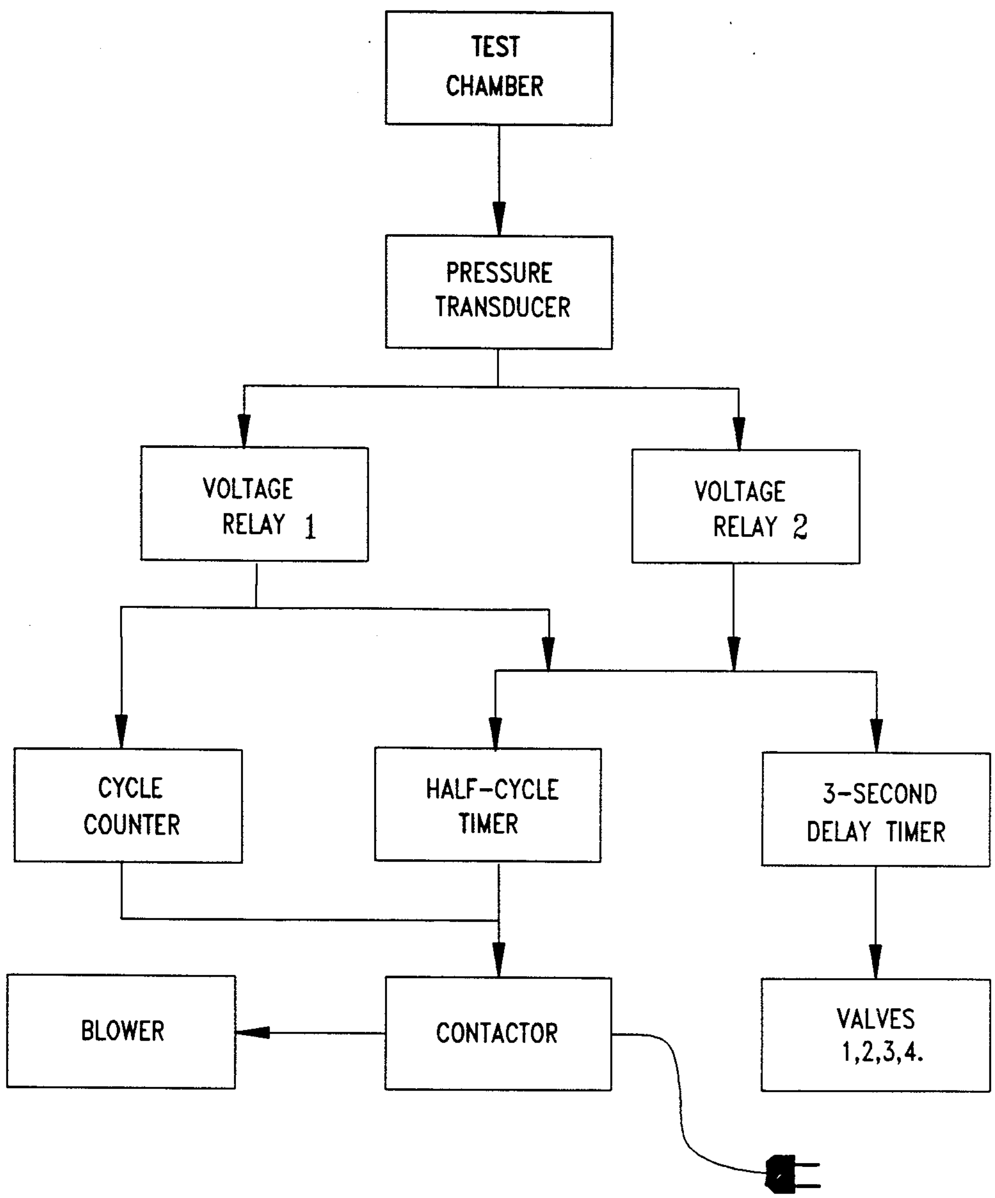


FIGURE 7. Schematic of control system.

2.2.2 Adjustable Voltage-Metering Relay

The purpose of the adjustable voltage-metering relay is to meter the rectified pressure transducer voltage and turn on its relay when the correct voltage (test pressure) is reached. This is the signal which initiates the flow reversal process. The voltage level at which the relay turns on is set during the initialization process. A desirable feature of this component is that once its relay is turned on, it does not shut off until the input voltage drops to below 90% of the set value. Thus, minor fluctuations of the test chamber pressure near the set level do not cause the voltage relay to turn on and off which, since the relay is used to trip the cycling process, would otherwise result in sporadic flow reversals.

2.2.3 3-Second Delay Timer

The 3-second delay timer's function is to delay the air flow reversal for 3 s after the cyclic test pressure is reached (after the voltage relay turns on) to comply with the ASTM E 1233-88 specification that the cyclic test pressure be held for 3 s during each half-cycle. The timer begins timing as soon as the voltage relay turns on and at the end of 3 s, it turns on its own relay, signalling the solenoid valves, used to control the compressed air flow to the pneumatic actuators, to reconfigure such that the flow-direction valves are positioned to provide the opposite pressure.

2.2.4 Programmable Cycle Counter

The purpose of the programmable cycle counter is to stop the cycling process by shutting off the blower at the completion of the desired number of cycles. The counter is programmed during the initialization process and is incremented every time the voltage relay 1 is turns on. Upon completion of the requisite number of cycles, the counter's relay turns on, shutting off the blower by sending a signal to open the contractor (a type of heavy-duty relay) through which the blower draws its power.

2.2.5 Half-Cycle Timer

The half-cycle timer is used to shut off the blower if a half-cycle takes longer than 30 s to complete. This feature was incorporated to reduce the possibility of glass breakage, as recommended in ASTM E 1233-88, and to indicate the occurrence of a major test specimen failure. The latter function is achieved based on the premise that a half-cycle would only substantially increase in length if a pressure loss developed in the system, most likely indicating a structural failure in the test specimen. This timer's reset signal is provided by the voltage relays turning on. If the timer is allowed to exceed 30 s without being reset, its relay shuts off the blower via the aforementioned contactor.

2.2.6 Programmable Logical Controller

Two routes were considered when designing the latter part of the control system (Sections 2.2.3, 2.2.4 and 2.2.5). The first was to use a dedicated system consisting of two programmable timers and a programmable counter for the 3-second and half-cycle timers, and the cycle counter, respectively. The other alternative was to use a programmable logical controller (PLC) to perform the same functions. Basically, PLC's are devices which serve the purpose of a series of relays, timers, counters, etc. using a microprocessor to control these functions. As their name implies they are programmable in a simple language based on electrical step-ladder diagrams.

The PLC was chosen over the dedicated system because the PLC allows a wide deviation from the original project parameters while the dedicated system does not. This means that not only can the PLC still be used if the project parameters change from design, but also that the PLC can be removed from the apparatus and used anywhere else where relays, timers, counters, etc. are required.

2.2.7 Solenoid Valves

Solenoid valves were required to control the compressed air flow to the pneumatic actuators in order to open and close the flow-direction valves. Separate solenoid valves were connected to each actuator, allowing individual control of each flow-direction valve, if desired. The PLC is responsible for reconfiguring the solenoid valves and thus the flow-direction valves every half cycle.

2.2.8 Contactor

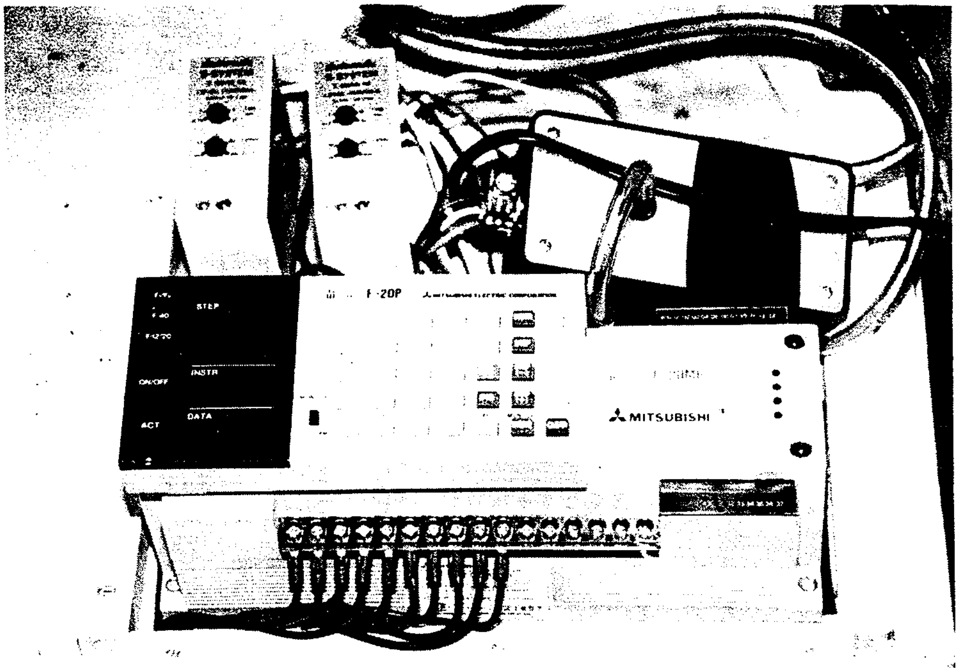
The contactor's function is to cut electricity to the blower if it receives a signal from either the cycle counter or the half-cycle timer. A contactor is a type of heavy-duty relay designed for motor loads. The model selected for this project was required to be able handle both single- and three-phase alternating current because the standard blowers are of both types.

2.2.9 Control Switches

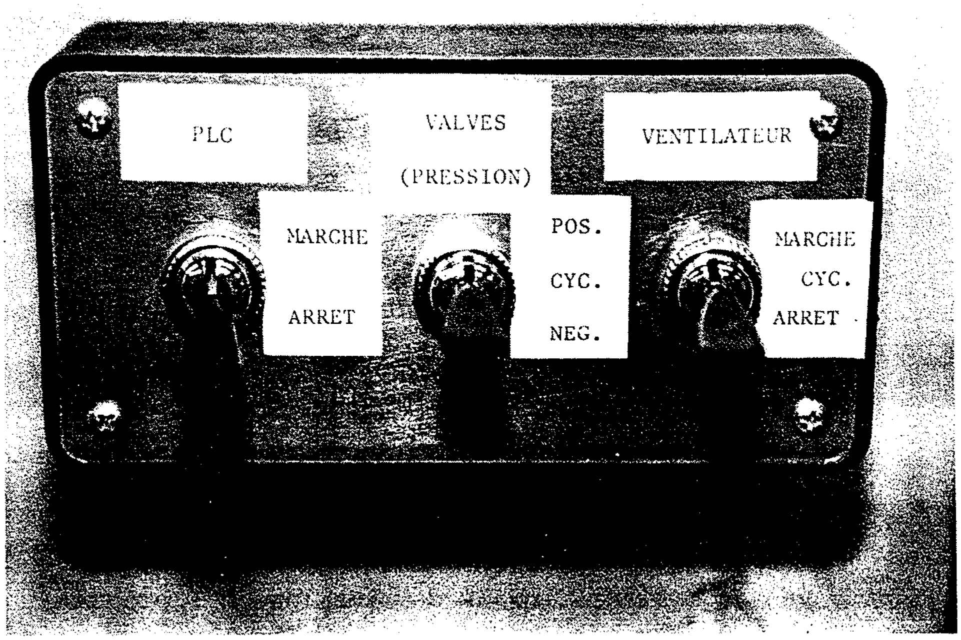
The control switches, as shown in Photograph no. 19 were incorporated to allow the cycling system to be manually overridden.

The "PLC" switch has two positions: "arrêt" ("stop") and "marche" ("run"). In the "arrêt" position, the PLC is not performing its internal program. In this mode, the PLC may be programmed. In the "marche" position, the PLC is performing its internal program. The switch must be in this position for automatic pressure cycling or for the operation of the other two switches on the panel. The PLC may not be programmed in this mode.

The "valves (pression)" ("valves "pressure)") switch has three positions: "pos." ("positive"), "neg." ("negative"), and "cyc." ("cycle"). With the PLC switch in the "marche" position, the "valves (pression)" switch allows the operator to control the configuration of the flow-direction valves. Thus the "pos." and "neg." switch positions configure the valves to supply positive and negative pressure to the test chamber, respectively. With this switch in the "cyc." position, the PLC automatically cycles the valve configuration as per its internal program.



Photograph no. 18: Control system



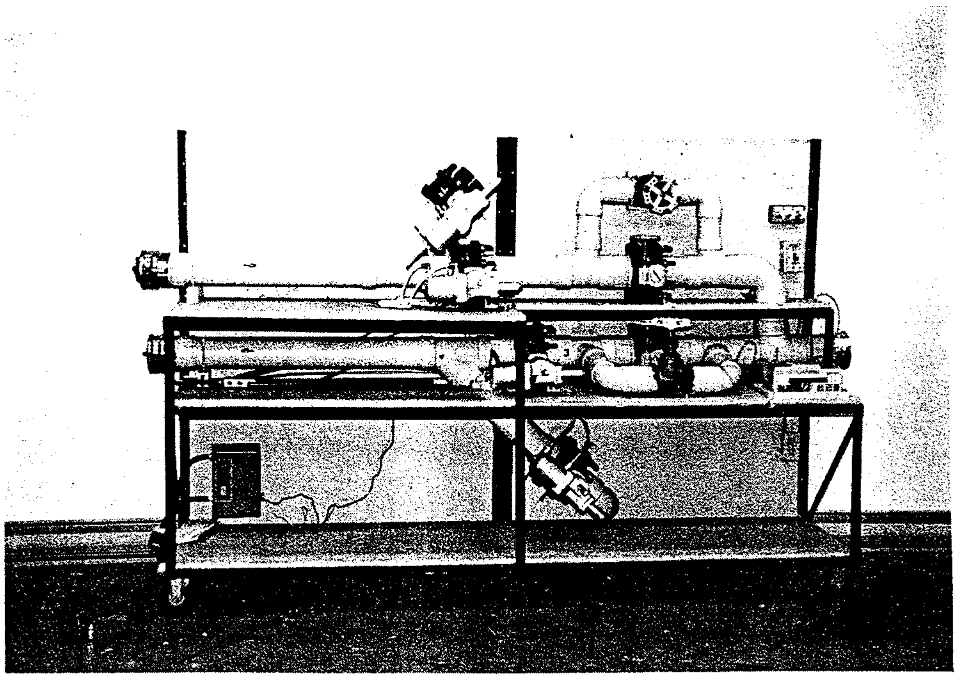
Photograph no. 19: Control switches

The "ventilateur" ("blower") switch also has three positions: "marche" ("run"), "arrêt" ("stop"), and "cyc." ("cycle"). With the PLC swithe in the "marche" position, the "ventilateur" switch allows the operator to control the blower. The "marche" and "arrêt" positions turn the blower on and off, respectively. The "cyc." position allows the PLC to control the blower as per its internal program (i.e. it will shut the blower off if the half-cycle counter or the half-cycle timer reach their programmed values).

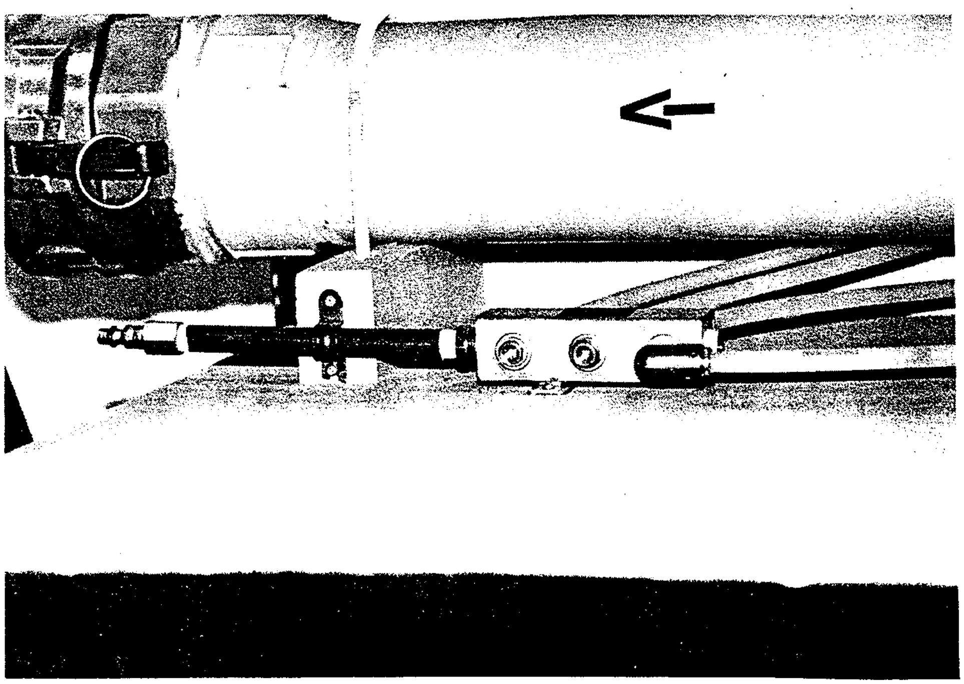
2.3 APPARATUS MOUNTING

The main consideration in the mounting of the pipe-line and other components was that the entire assembly should be mobile enough to be easily moved from one blower/test chamber set-up to another. Other considerations included easy access to the control valves and the PLC for adjustments, apparatus stability, and pipe support strength requirements.

The final product is shown in Photograph no. 20. The frame has a width of 0.6 m and a height of 1.7 m, allowing it to pass easily through doors. Its length is 2.4 m, allowing it to fit into the bed of a full-size pick-up truck for transport between test facilities. The cut-out in the right hand side of the upper shelf makes access to the lower pipe-line's control valves and the PLC very easy. This design provides good stability since its centre of gravity is near the centre of the apparatus. Also, shelf-mounting of the pipe-line means that strong pipe supports are required only for the three valves which are not resting on shelves.



Photograph no. 20: Cyclic air pressure delivery device.



Photograph no. 21: Quick-connect pneumatic fitting with plenum.

The frame was mounted on casters for ease of mobility. Swivel casters were mounted on one end and fixed casters on the other. This arrangement results in good directional stability when in motion. The casters selected were large enough (5 inches in diameter) so that they would roll easily over surface irregularities and their tread was of a neoprene construction to provide low rolling resistance.

2.3.1. Quick-Connect Fittings

Quick-connect fittings are used for all of the external connections to the apparatus so that it can be quickly connected to, or disconnected from, any one of the blower-/test chamber set-ups. The pipe-line has female cam-look connectors and the flexible hoses for attachment to the blower and test chamber have corresponding male connectors. This allows for rapid installation and removal of the cycling apparatus. The compressed air hook-up is also a quick-connect fitting which runs into a plenum serving all four of the pneumatic actuators (see Photograph no. 21). The pressure transducer connects directly to the test chamber's manometer outlet via an attached length of flexible pressure tube. Finally, all of the electricity for the system is supplied through one extension cord attached to the back of the apparatus.

AIR-INS inc.

APPENDIX "C"

AIR-INS inc.

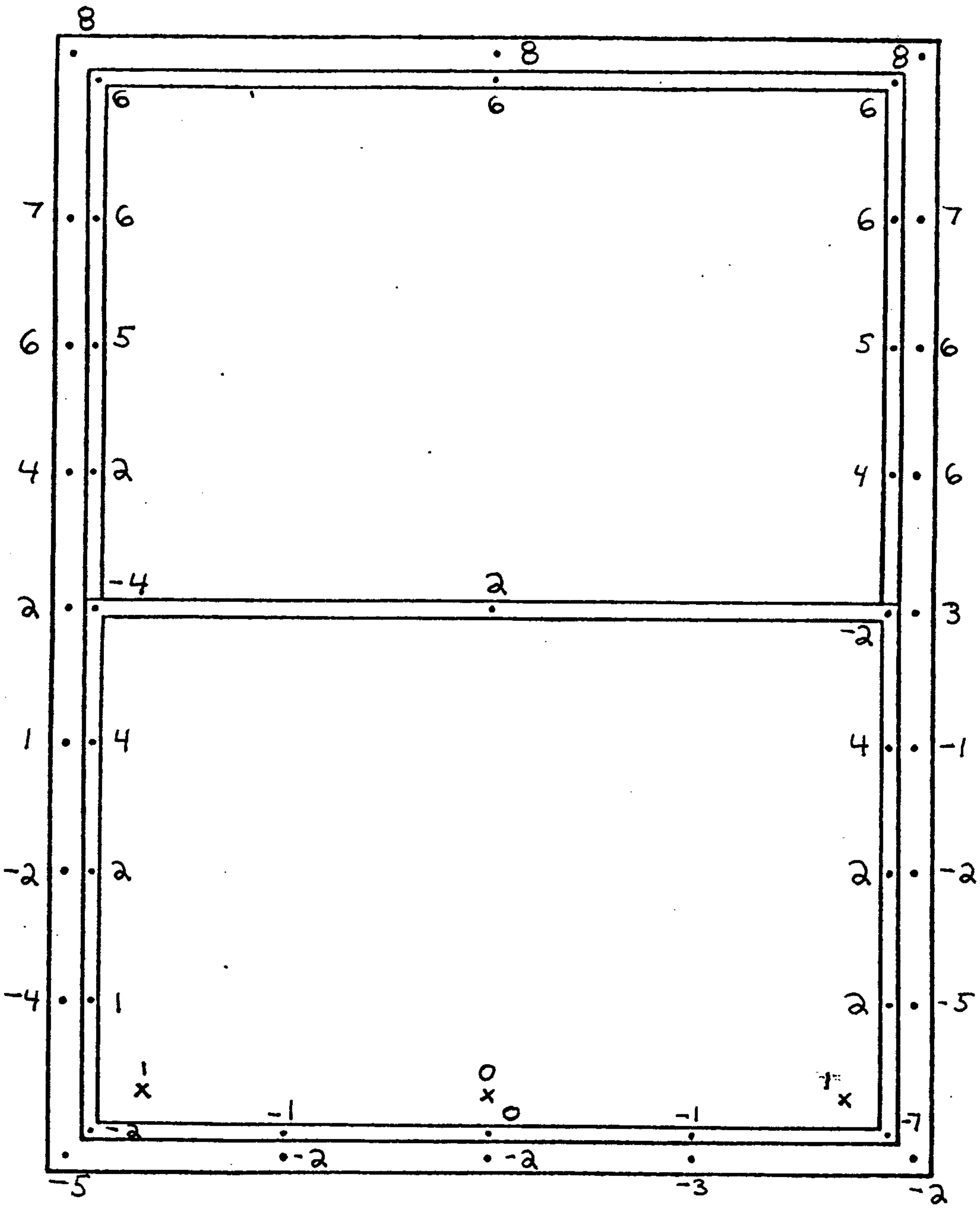
INITIAL TEST

CYCLE: 0

C1

PC-1

CYC: O



REMARQUES

- épaisseur de la lame d'air = ____mm
- température de l'air sur le côté chaud de la fenêtre = 20 °C
- température de l'air sur le côté froid de la fenêtre = -30 °C

AIR INS Inc.

titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)		
dessiné par / dwg. by	A.P.	feuille no. de / sheet no. of	
vérifié par / chk. by	A.P.	légende no. / mtl. list no.	
échelle / scale	date	dessin no. / dwg. no.	

PC·1 CYC:0

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

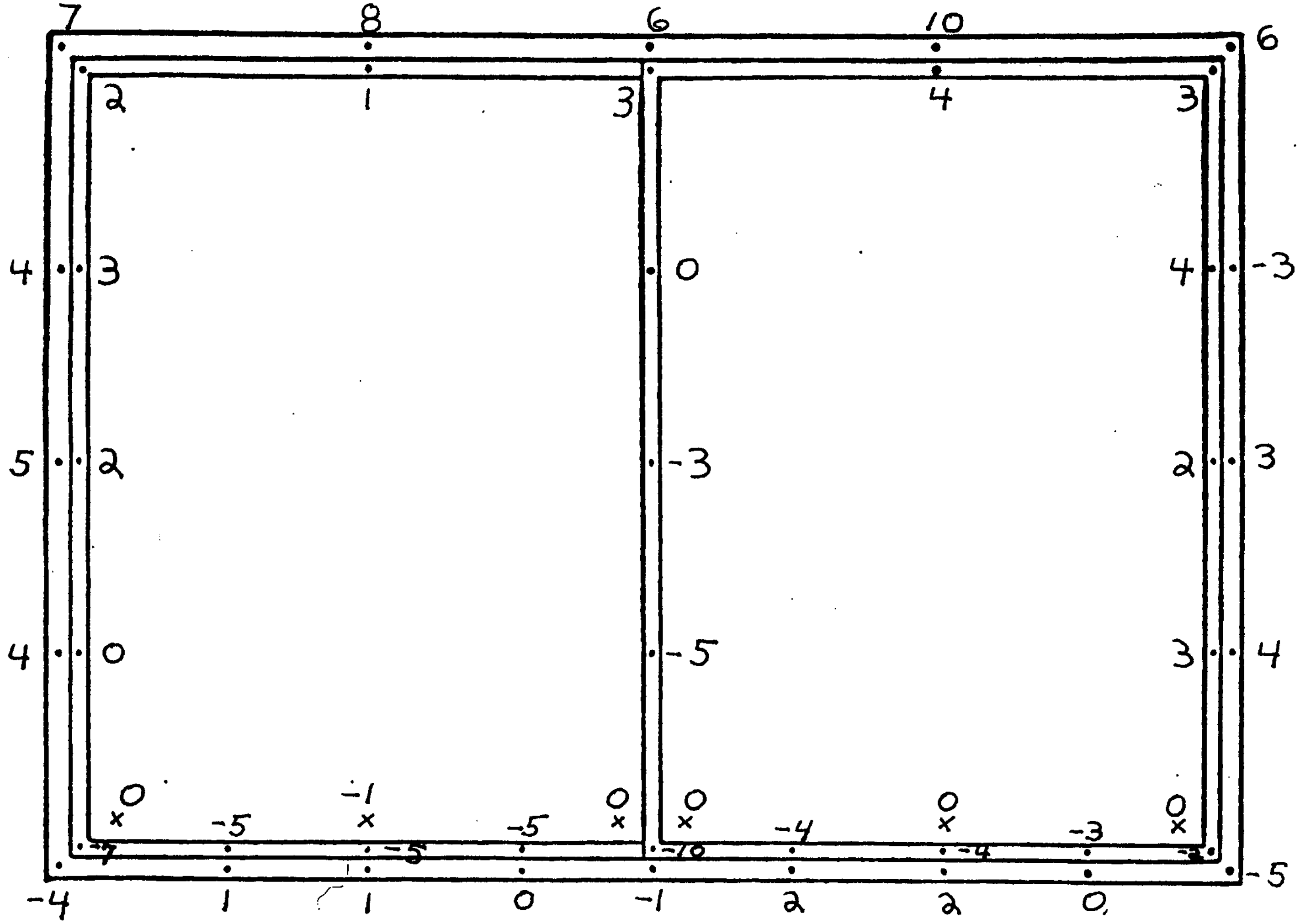
$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = 1
- Coldest frame temperature (Tf) = -5
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 31
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 25
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig = \frac{31}{50} \times 100$ = 62
- Temperature index for the frame $If = \frac{25}{50} \times 100$ = 50

The minimum acceptable value of I is 40

C3

PC-8
CYC: O



REMARQUES

- épaisseur de la lame d'air = ________ mm
- température de l'air sur le côté chaud de la fenêtre = 20 °C
- température de l'air sur le côté froid de la fenêtre = -30 °C

AIR INS Inc.			
titre / title	DISTRIBUTION DES TEMPERATURES (COTE CHAUD)		
dessiné par / dwg. by	A.P.	feuille no. de / sheet no. of	
verifié par / chk. by	A.P.	legende no. / mat. list no.	
echelle / scale —	date	dessin no. / dwg. no.	

PC-8 CYC:0

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

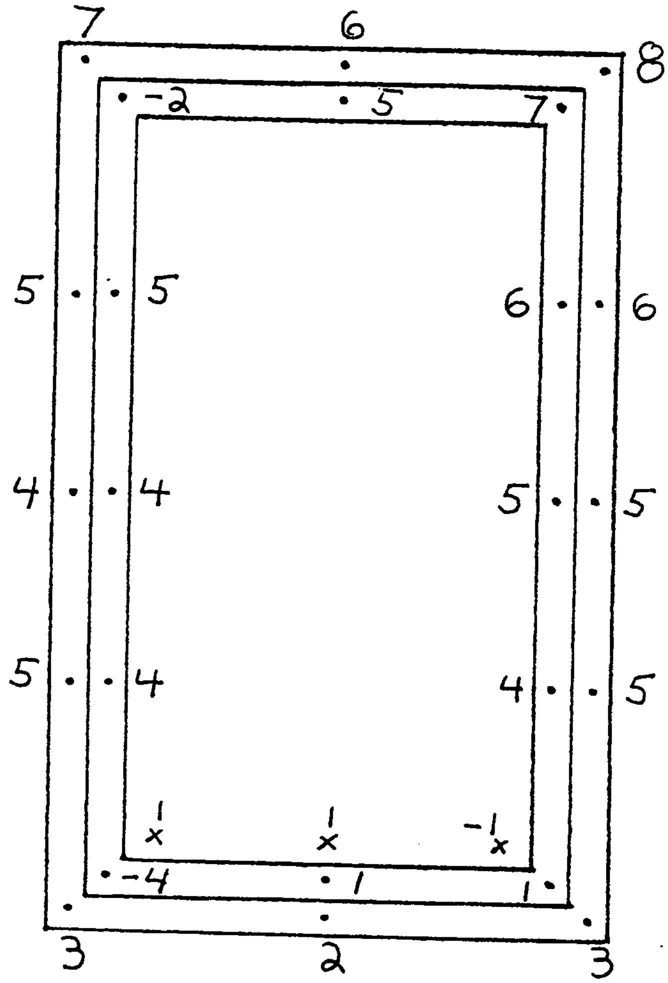
For the frame

$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = 0
- Coldest frame temperature (Tf) = -10
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 30
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 20
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig= \frac{30}{50} \times 100$ = 60
- Temperature index for the frame $If= \frac{20}{50} \times 100$ = 40

The minimum acceptable value of I is 40

PC-9 CYC: 0



REMARQUES:

- Température de l'air sur le côté chaud de la fenêtre = 20
- Température de l'air sur le côté froid de la fenêtre = -30
- Epaisseur de la lame d'air =

AIR INS Inc.		
titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)	
dessiné par / dwg. by	A.P.	feuille no. de / sheet no. of
vérifié par / chk. by	A.P.	légende no. / mtl. list no.
échelle / scale	date	dessin no. / dwg. no.

C6

PC-9 CYC:0

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

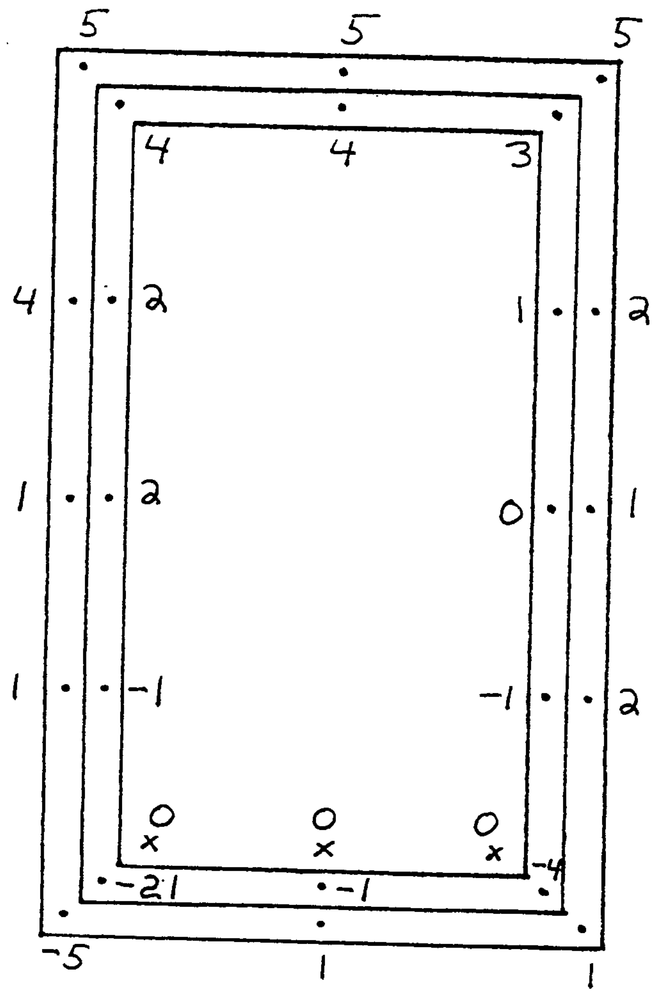
$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = 0
- Coldest frame temperature (Tf) = -4
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 30
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 26
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig = \frac{30}{50} \times 100$ = 60
- Temperature index for the frame $If = \frac{26}{50} \times 100$ = 52

The minimum acceptable value of I is 40

C7

PC-10
CYC: O



REMARQUES:

- Température de l'air sur le côté chaud de la fenêtre = 20
- Température de l'air sur le côté froid de la fenêtre = -30
- Epaisseur de la lame d'air =

AIR INS Inc.

titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)		
dessiné par / dwg. by	A.P.	feuille no. / sheet no.	de / of
vérifié par / chk. by	A.P.	légende no. / mtl. list no.	
échelle / scale	date	dessin no. / dwg. no.	

PC-10 CYC: O

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

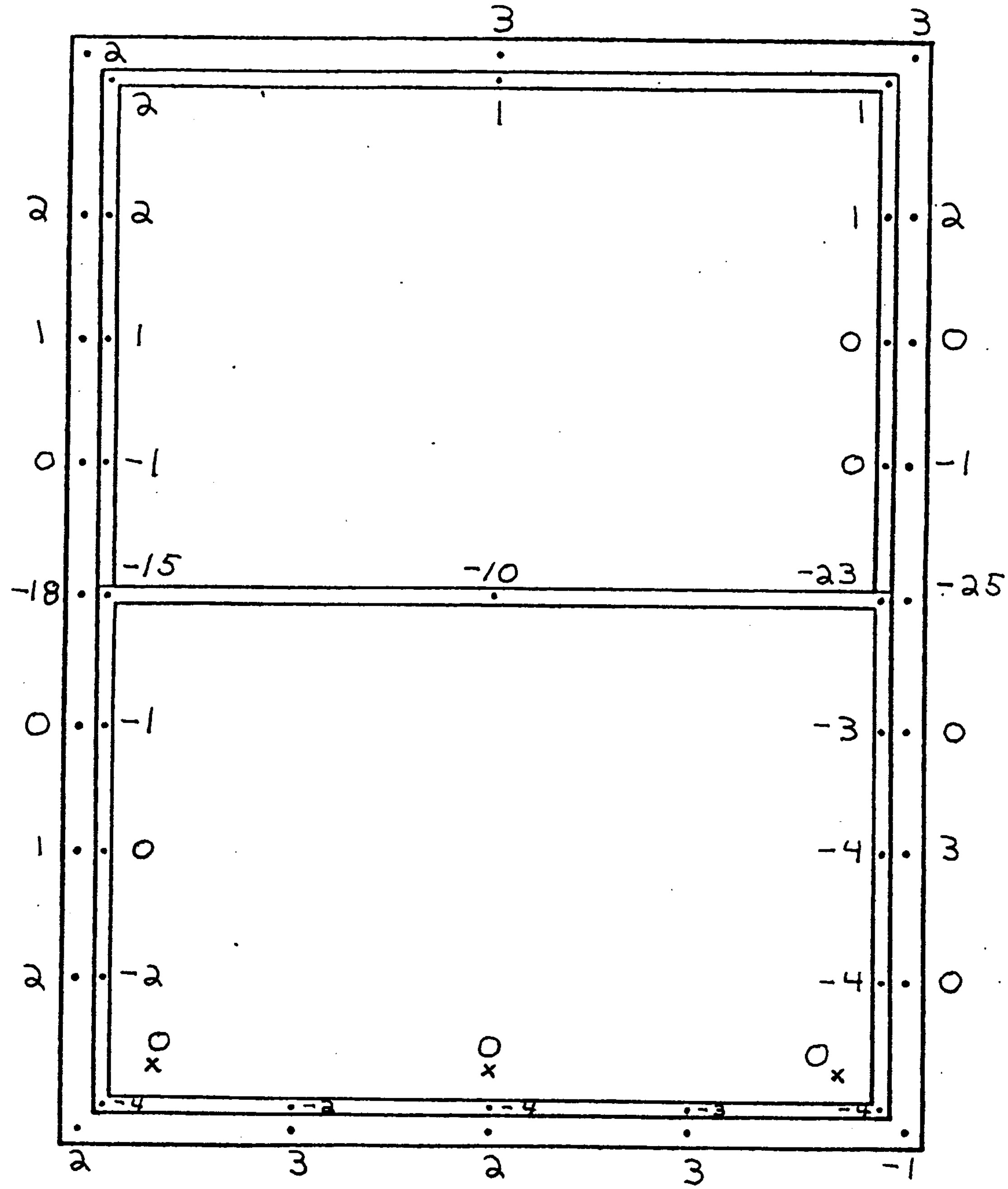
$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = 0
- Coldest frame temperature (Tf) = -21
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 30
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 9
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig = \frac{30}{50} \times 100$ = 60
- Temperature index for the frame $If = \frac{9}{50} \times 100$ = (18)

The minimum acceptable value of I is (40)

C9

PC-11 CYC: O



REMARQUES

- épaisseur de la lame d'air = ____ mm
- température de l'air sur le côté chaud de la fenêtre = 20 °C
- température de l'air sur le côté froid de la fenêtre = -30 °C

AIR INS Inc.			
titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)		
dessiné par / dwg. by	A.P.	feuille no. de / sheet no. of	
vérifié par / chk. by	A.P.	légende no. / mtl. list no.	
échelle / scale	date	dessin no. / dwg. no.	

PC11 CYC: O

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

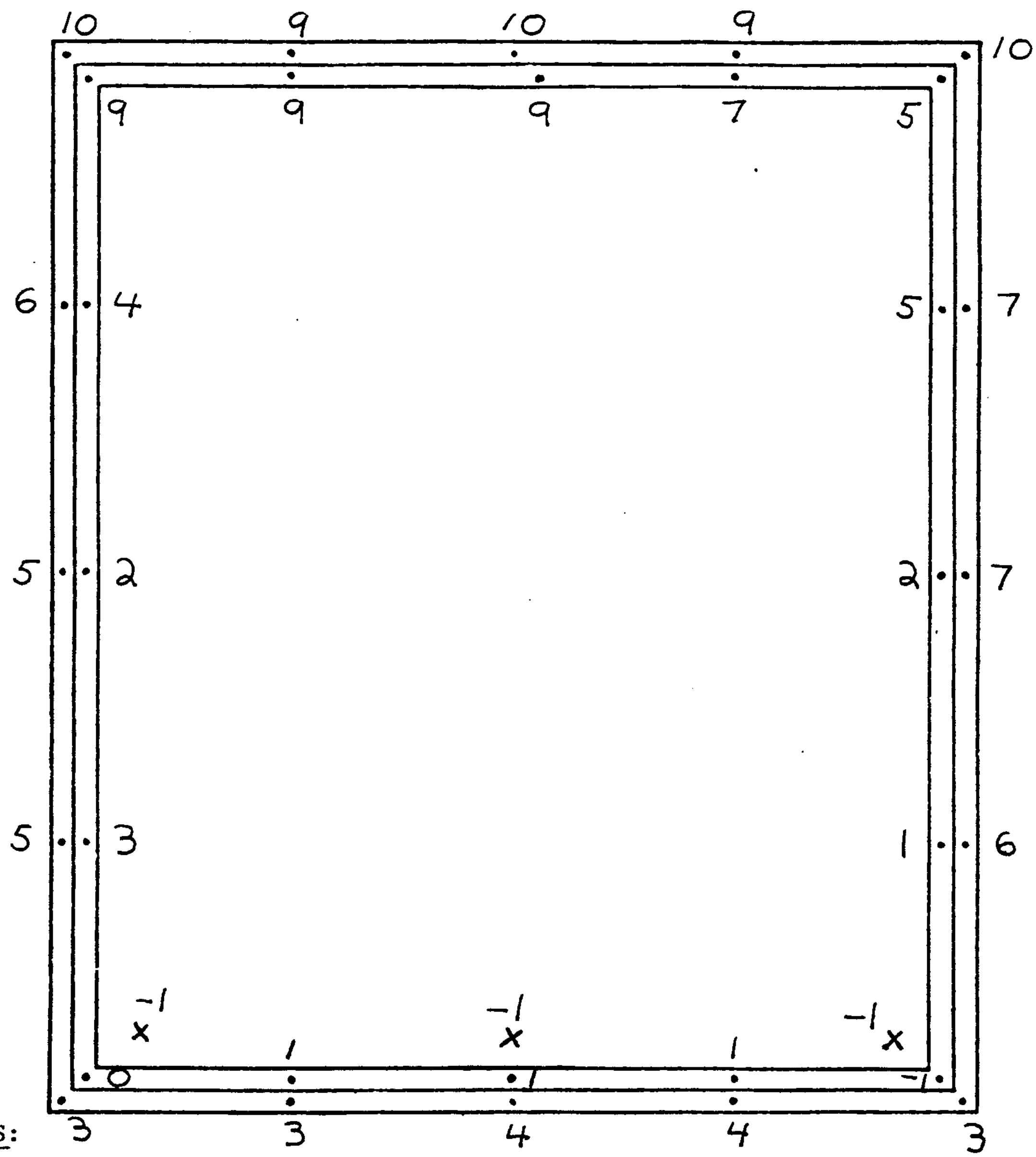
$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = 0
- Coldest frame temperature (Tf) = -25
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 30
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 5
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig = \frac{30}{50} \times 100$ = 60
- Temperature index for the frame $If = \frac{5}{50} \times 100$ = 10

The minimum acceptable value of I is 40

C11

PC-13 CYC: 0



REMARQUES:

- Température de l'air sur le côté chaud de la fenêtre = 20
- Température de l'air sur le côté froid de la fenêtre = -30
- Epaisseur de la lame d'air =

AIR INS Inc.		
titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)	
dessiné par / dwg. by	A.P.	feuille no. de / sheet no. of
vérifié par / chk. by	A.P.	légende no. / mtl. list no.
échelle / scale	date	dessin no. / dwg. no.

C12

PC 13 CYC: O

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

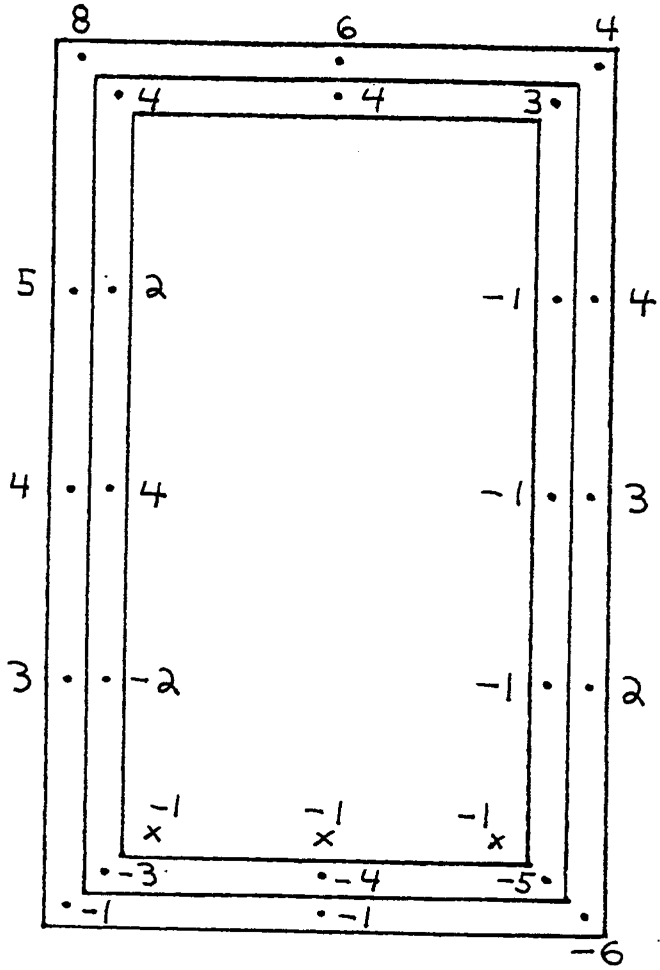
$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = -1
- Coldest frame temperature (Tf) = -1
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 29
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 29
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig = \frac{29}{50} \times 100$ = 58
- Temperature index for the frame $If = \frac{29}{50} \times 100$ = 58

The minimum acceptable value of I is 40

C13

PC-15 CYC:O



REMARQUES:

- Température de l'air sur le côté chaud de la fenêtre = 20
- Température de l'air sur le côté froid de la fenêtre = -30
- Epaisseur de la lame d'air =

AIR INS Inc.			
titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)		
dessiné par / dwg. by	A.P.	feuille no. de / sheet no. of	
vérifié par / chk. by	A.P.	légende no. / mtl. list no.	
échelle / scale	date	dessin no. / dwg. no.	

C14

PC-15 CYC:0

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

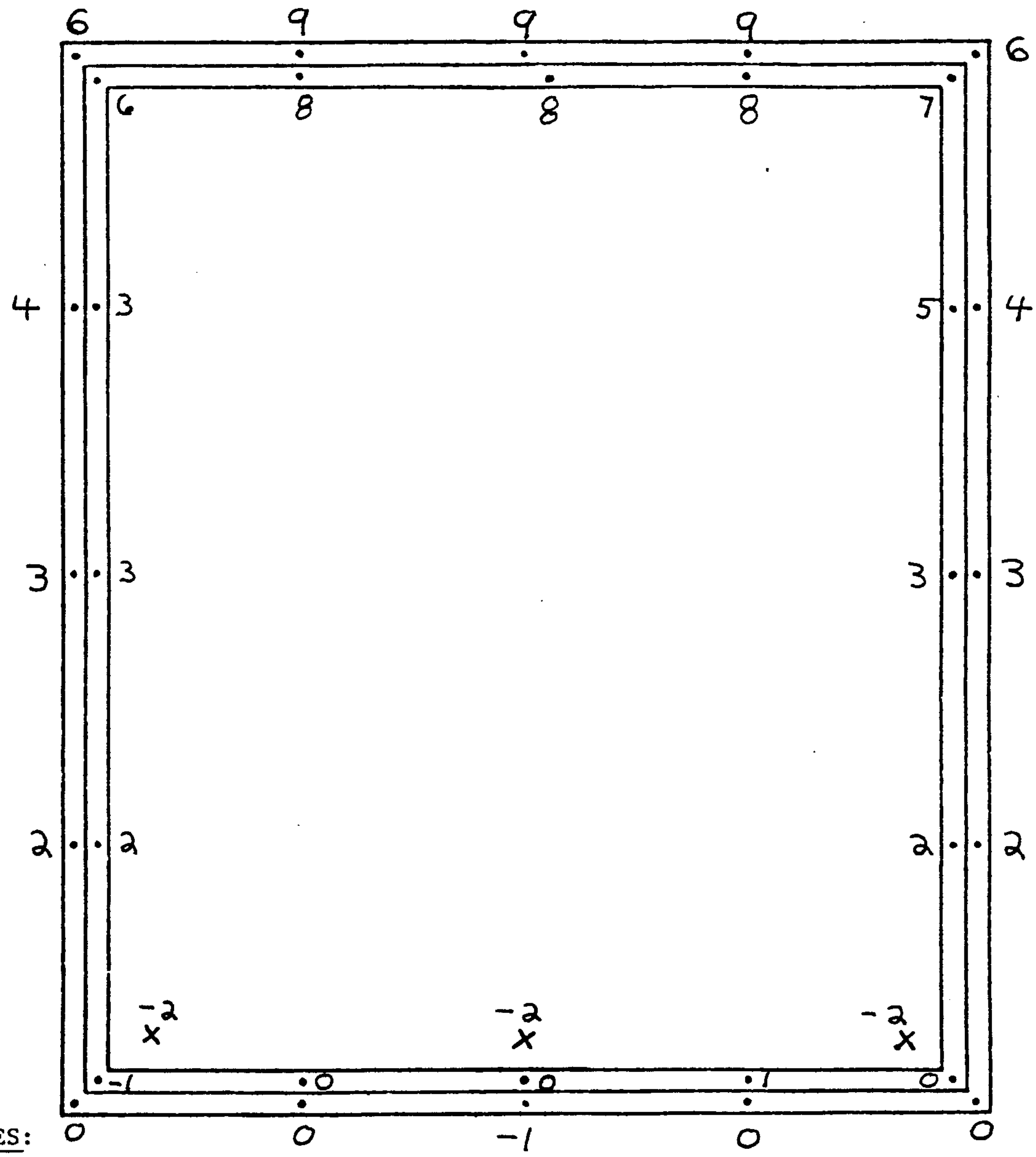
$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = -1
- Coldest frame temperature (Tf) = -6
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 29
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 24
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig = \frac{29}{50} \times 100$ = 58
- Temperature index for the frame $If = \frac{24}{50} \times 100$ = 48

The minimum acceptable value of I is 40

C15

PC-16 CYC: 0



REMARQUES:

- Température de l'air sur le côté chaud de la fenêtre = 20
- Température de l'air sur le côté froid de la fenêtre = -30
- Epaisseur de la lame d'air =

AIR INS Inc.		
titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)	
dessiné par / dwg. by	A.P.	feuille no. de / sheet no. of
vérifié par / chk. by	A.P.	légende no. / mtl. list no.
échelle / scale	date	dessin no. / dwg. no.

C16

PC-16 CYC: 0

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

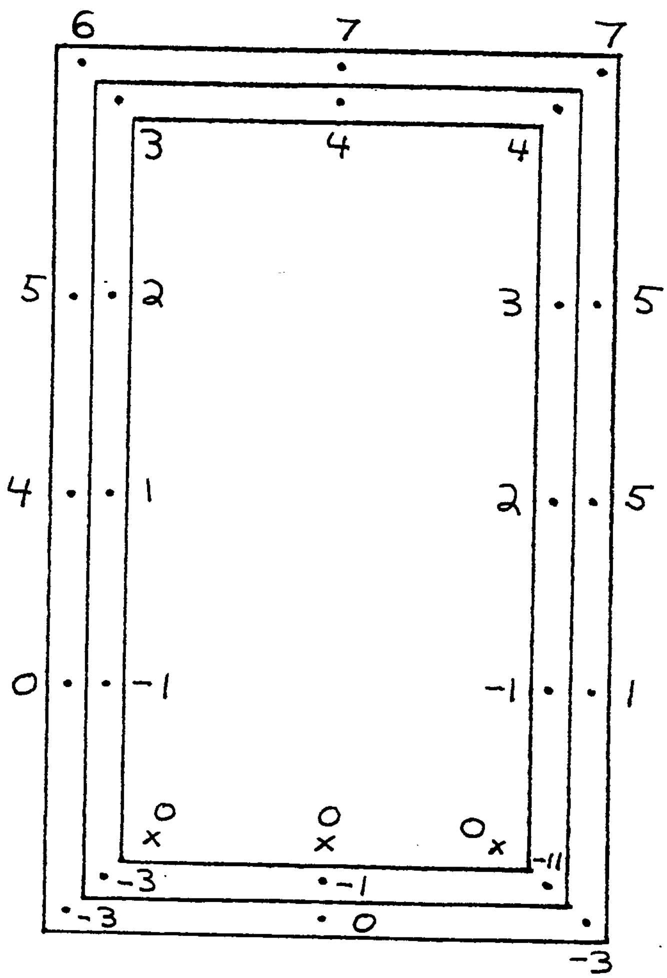
$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = -2
- Coldest frame temperature (Tf) = -1
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 28
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 29
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig = \frac{28}{50} \times 100$ = 56
- Temperature index for the frame $If = \frac{29}{50} \times 100$ = 58

The minimum acceptable value of I is 40

C17

PC-17 CYC:0



REMARQUES:

- Température de l'air sur le côté chaud de la fenêtre = 20
- Température de l'air sur le côté froid de la fenêtre = -30
- Epaisseur de la lame d'air =

AIR INS Inc.

titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)		
dessiné par / dwg. by	A.P.	feuille no. / sheet no.	de / of
vérifié par / chk. by	A.P.	légende no. / mtl. list no.	
échelle / scale	date	dessin no. / dwg. no.	

C18

PC-17 CYC: O

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

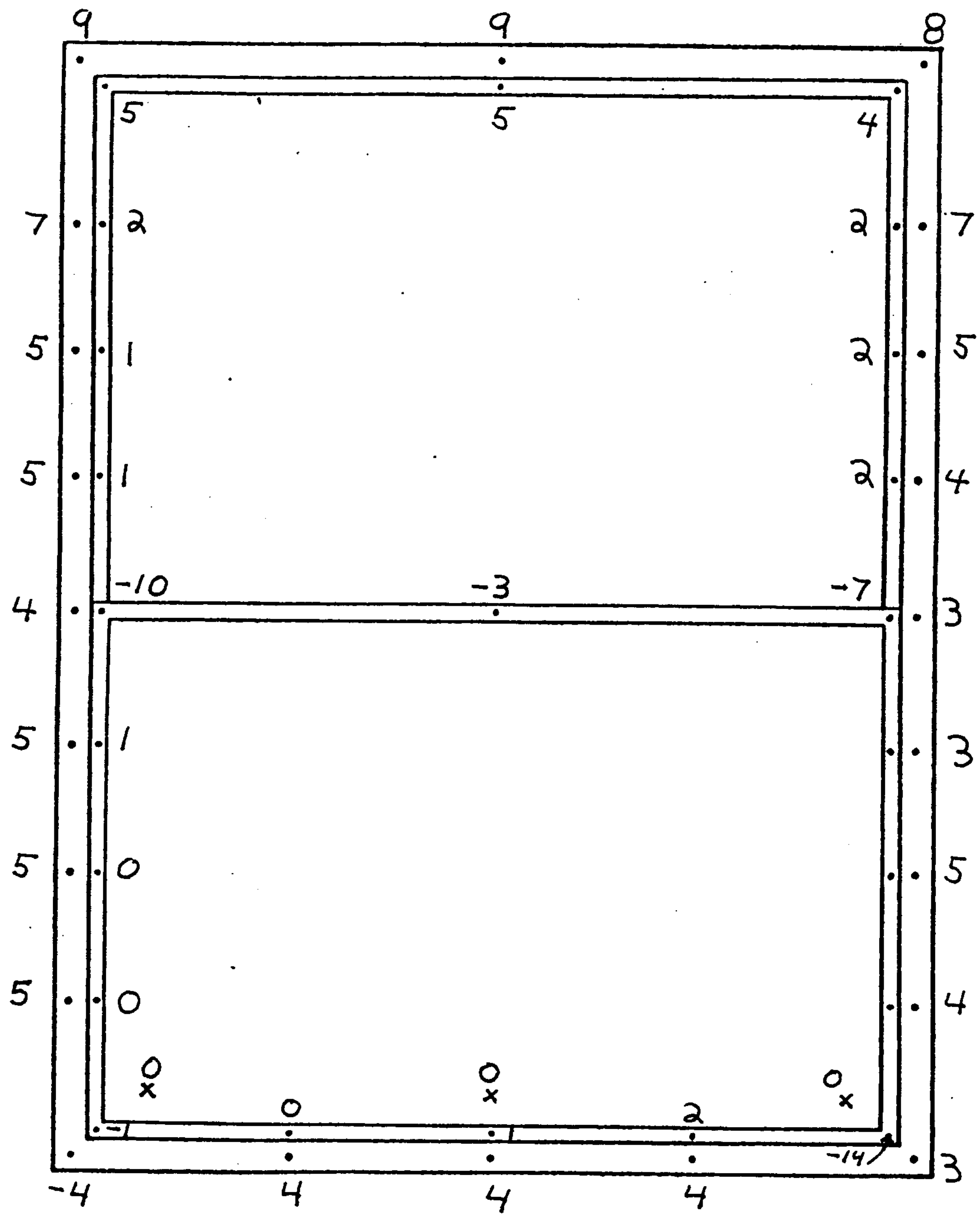
$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = 0
- Coldest frame temperature (Tf) = -11
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 30
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 19
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig = \frac{30}{50} \times 100$ = 60
- Temperature index for the frame $If = \frac{19}{50} \times 100$ = 38

The minimum acceptable value of I is 40

C19

PC-18 CYC:0



REMARQUES

- épaisseur de la lame d'air = ____mm
- température de l'air sur le côté chaud de la fenêtre = 20 °C
- température de l'air sur le côté froid de la fenêtre = -30 °C

AIR INS Inc.		
titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)	
dessiné par / dwg. by	A.P.	feuille no. de / sheet no. of
vérifié par / chk. by	A.P.	légende no. / mtl. list no.
échelle / scale	date	dessin no. / dwg. no.

C20

PC-18 CYC.: 0

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = 0
- Coldest frame temperature (Tf) = -14
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 30
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 16
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig = \frac{30}{50} \times 100$ = 60
- Temperature index for the frame $If = \frac{16}{50} \times 100$ = 32

The minimum acceptable value of I is 40

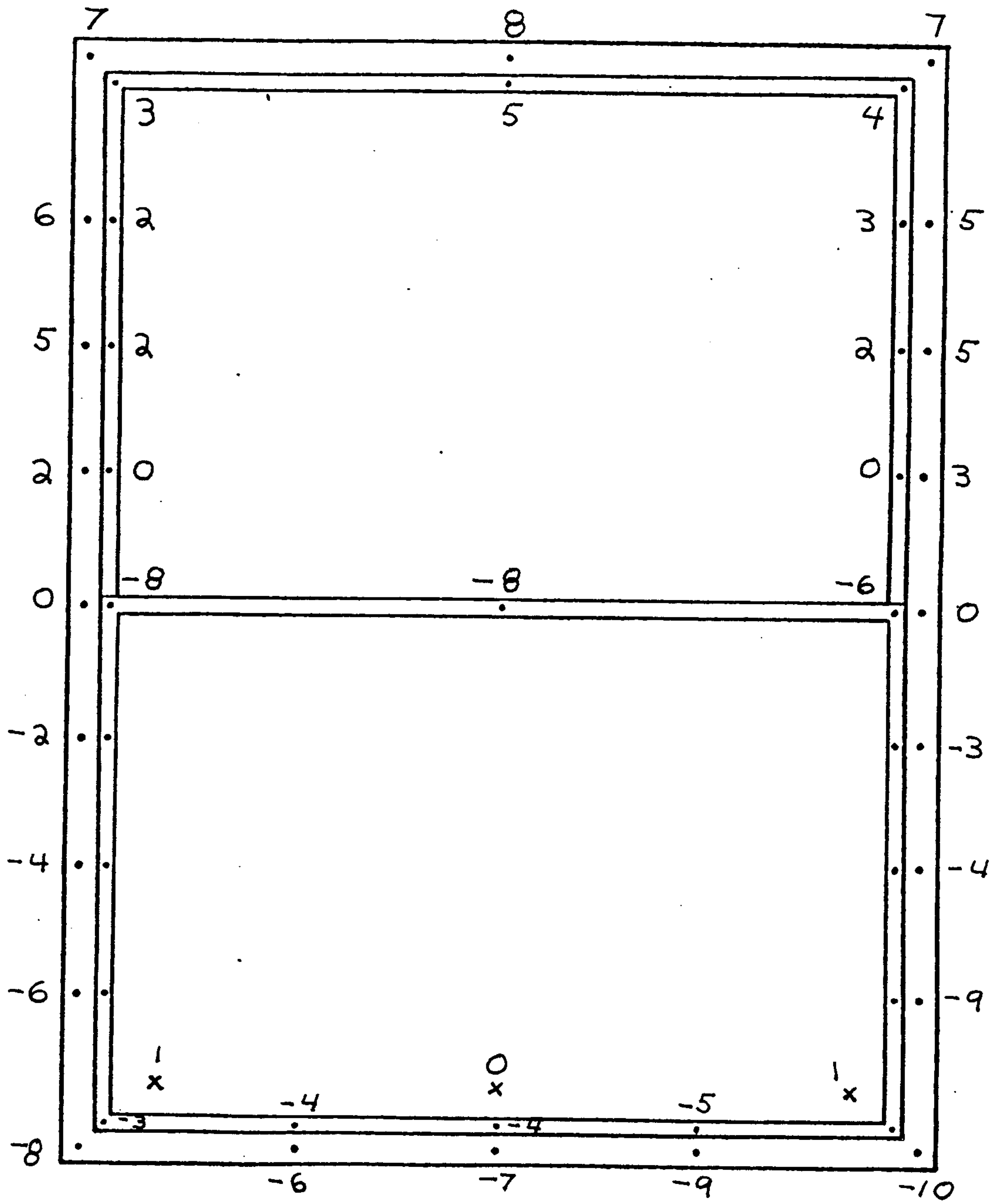
AIR-INS inc.

FINAL TEST

2000 CYCLES

C21

PC-1 CYC: 2000



REMARQUES

- épaisseur de la lame d'air = ____mm
- température de l'air sur le côté chaud de la fenêtre = 20 °C
- température de l'air sur le côté froid de la fenêtre = -30 °C

AIR INS Inc.		
titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)	
dessiné par / dwg. by	A.P.	feuille no. de / sheet no. of
vérifié par / chk. by	A.P.	légende no. / mtl. list no.
échelle / scale	date	dessin no. / dwg. no.

PC-1 CYC: 2000

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

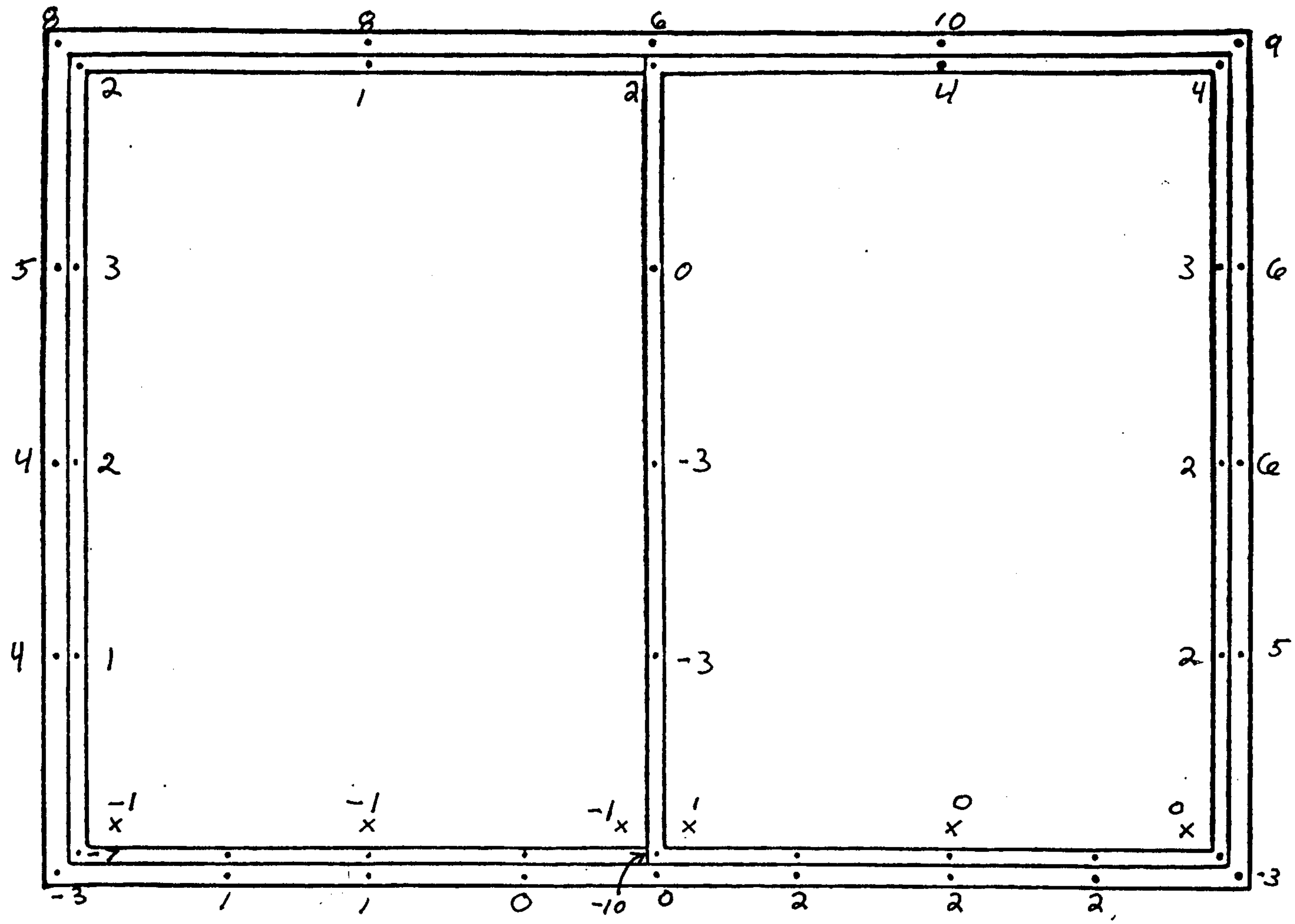
$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = 0
- Coldest frame temperature (Tf) = -10
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 30
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 20
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig = \frac{30}{50} \times 100$ = 60
- Temperature index for the frame $If = \frac{20}{50} \times 100$ = 40

The minimum acceptable value of I is 40

PC-8 CYC: 2000

C23



REMARQUES

- épaisseur de la lame d'air = ______ mm
- température de l'air sur le côté chaud de la fenêtre = 20 °C
- température de l'air sur le côté froid de la fenêtre = -30 °C

AIR INS Inc.			
titre / title	DISTRIBUTION DES TEMPERATURES (COTE CHAUD)		
dessine par / dwg by	A.P.	feuille no. de / sheet no of	
verifie par / chk. by	A.P.	legende no. / mat list no.	
echelle / scale	—	date	dessin no. / dwg no.

PC-8 CYC: 2000

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

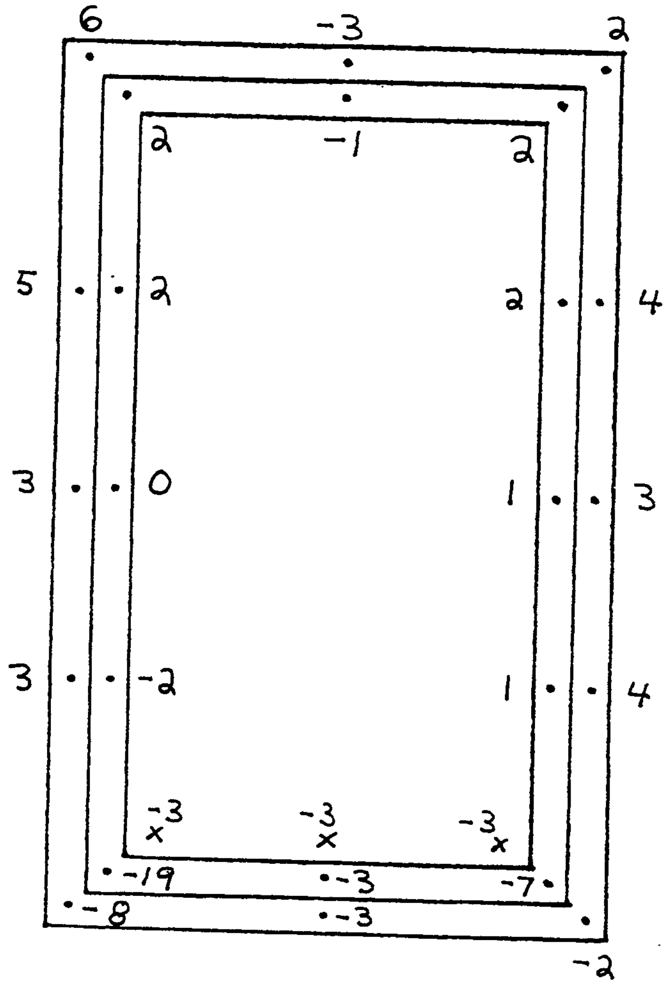
$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = -1
- Coldest frame temperature (Tf) = -10
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 29
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 20
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig = \frac{29}{50} \times 100$ = 58
- Temperature index for the frame $If = \frac{20}{50} \times 100$ = 40

The minimum acceptable value of I is 40

C 25

PC-9 CYC: 2000



REMARQUES:

- Température de l'air sur le côté chaud de la fenêtre = 20
- Température de l'air sur le côté froid de la fenêtre = -30
- Epaisseur de la lame d'air =

AIR INS Inc.		
titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)	
dessiné par / dwg. by: A.P.	feuille no. de / sheet no. of	
vérifié par / chk. by: A.P.	légende no. / mtl. list no.	
échelle / scale	date	dessin no. / dwg. no.

C26

PC-9 CYC: 2000

Determination of the "Temperature index" (I)

For the glass

$$I_g = \frac{T_g - T_c}{T_h - T_c} \times 100$$

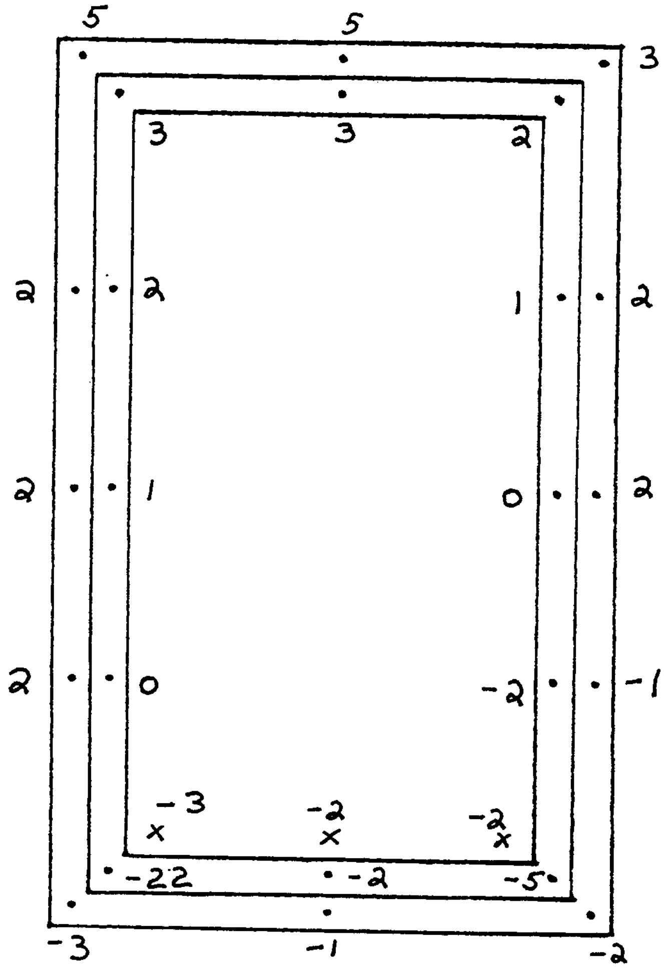
For the frame

$$I_f = \frac{T_f - T_c}{T_h - T_c} \times 100$$

- Average surface temperature of glass (Tg) = -3
- Coldest frame temperature (Tf) = -19
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 27
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 11
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $I_g = \frac{27}{50} \times 100$ = 54
- Temperature index for the frame $I_f = \frac{11}{50} \times 100$ = (22)

The minimum acceptable value of I is (40)

PC-10 CYC: 2000 C27



REMARQUES:

- Température de l'air sur le côté chaud de la fenêtre = 20
- Température de l'air sur le côté froid de la fenêtre = -30
- Epaisseur de la lame d'air =

AIR INS Inc.		
titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)	
dessiné par / dwg. by	A.P.	feuille no. de / sheet no. of
vérifié par / chk. by	A.P.	légende no. / mtl. list no.
échelle / scale	date	dessin no. / dwg. no.

C28

PC-10 CYC: 2000

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

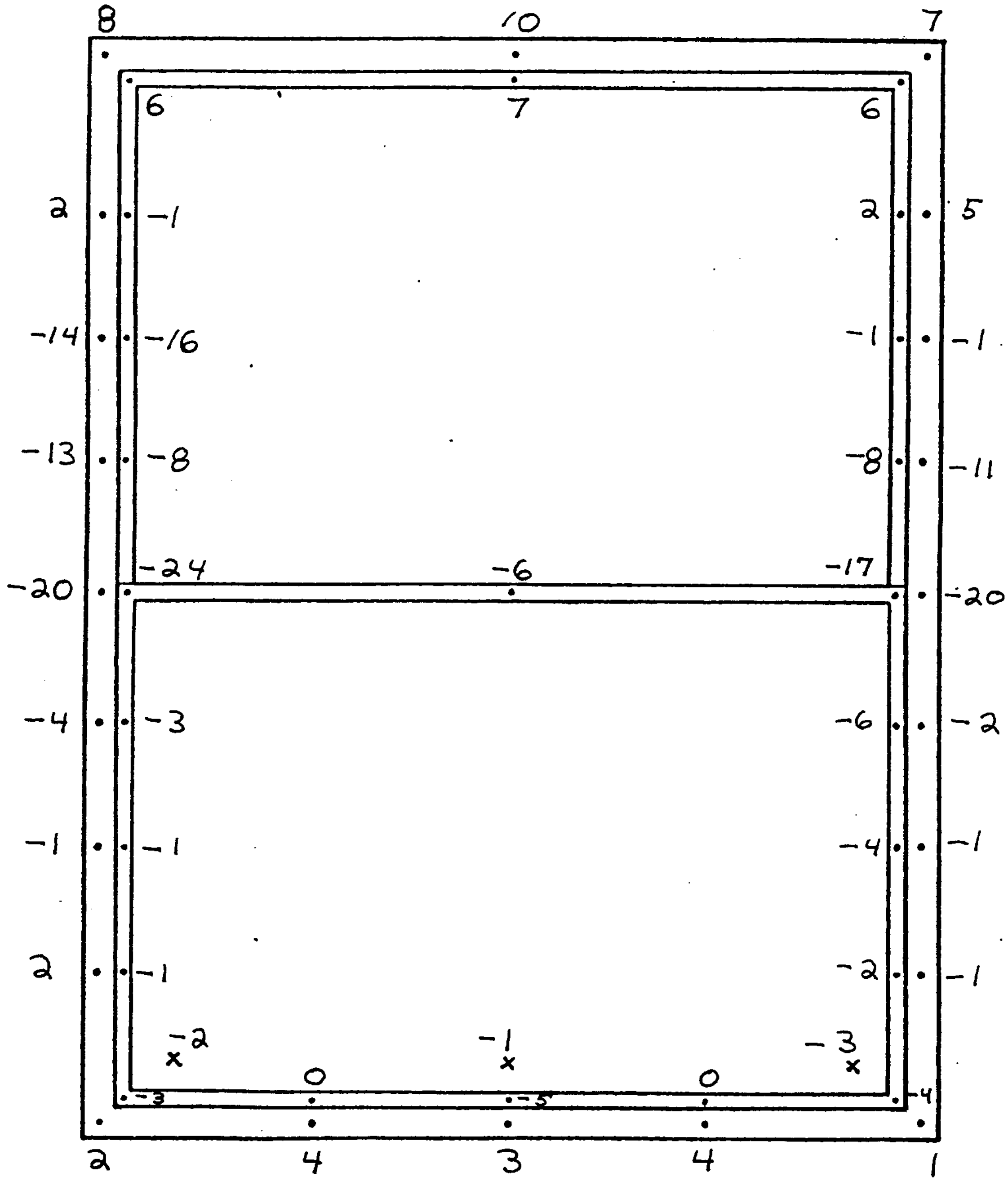
$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = -3
- Coldest frame temperature (Tf) = -22
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 27
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 8
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig = \frac{27}{50} \times 100$ = 54
- Temperature index for the frame $If = \frac{8}{50} \times 100$ = 16

The minimum acceptable value of I is 40

C29

PC-11 CYC: 2000



REMARQUES

- épaisseur de la lame d'air = _____ mm
- température de l'air sur le côté chaud de la fenêtre = 20 °C
- température de l'air sur le côté froid de la fenêtre = -30 °C

AIR INS Inc.

titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)		
dessiné par / dwg. by	A.P.	feuille no. de / sheet no. of	
vérifié par / chk. by	A.P.	légende no. / mtl. list no.	
échelle / scale	date	dessin no. / dwg. no.	

C30

PC-11 CYC: 2000

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

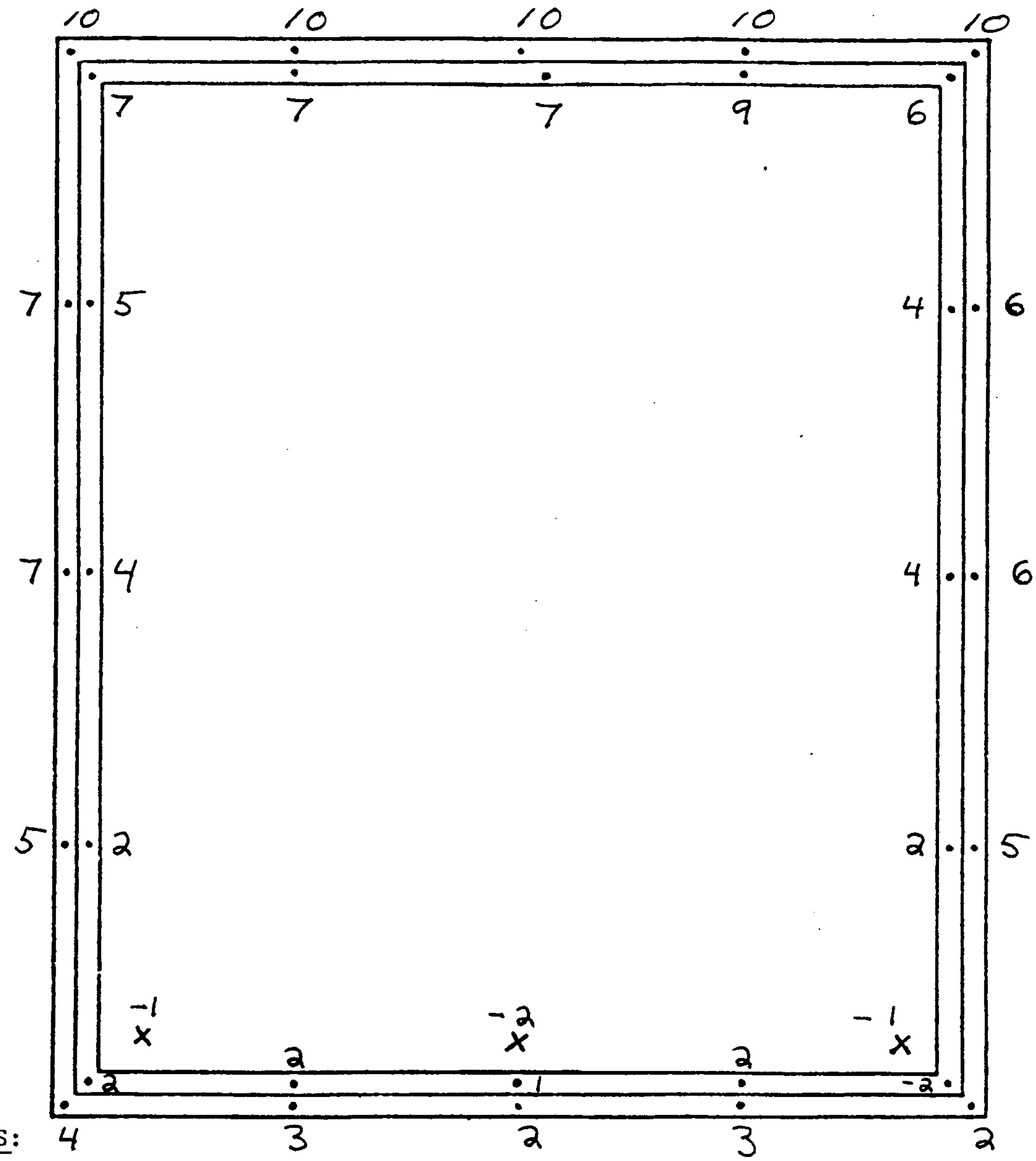
$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = -2
- Coldest frame temperature (Tf) = -24
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 28
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 6
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig = \frac{28}{50} \times 100$ = 56
- Temperature index for the frame $If = \frac{6}{50} \times 100$ = 12

The minimum acceptable value of I is 40

C31

PC-13 CYC: 2000



REMARQUES:

- Température de l'air sur le côté chaud de la fenêtre = 20
- Température de l'air sur le côté froid de la fenêtre = -30
- Epaisseur de la lame d'air =

AIR INS Inc.		
titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)	
dessiné par / dwg. by	A.P.	feuille no. de / sheet no. of
vérifié par / chk. by	A.P.	légende no. / mtl. list no.
échelle / scale	date	dessin no. / dwg. no.

C32

PC-13 CYC: 2000

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

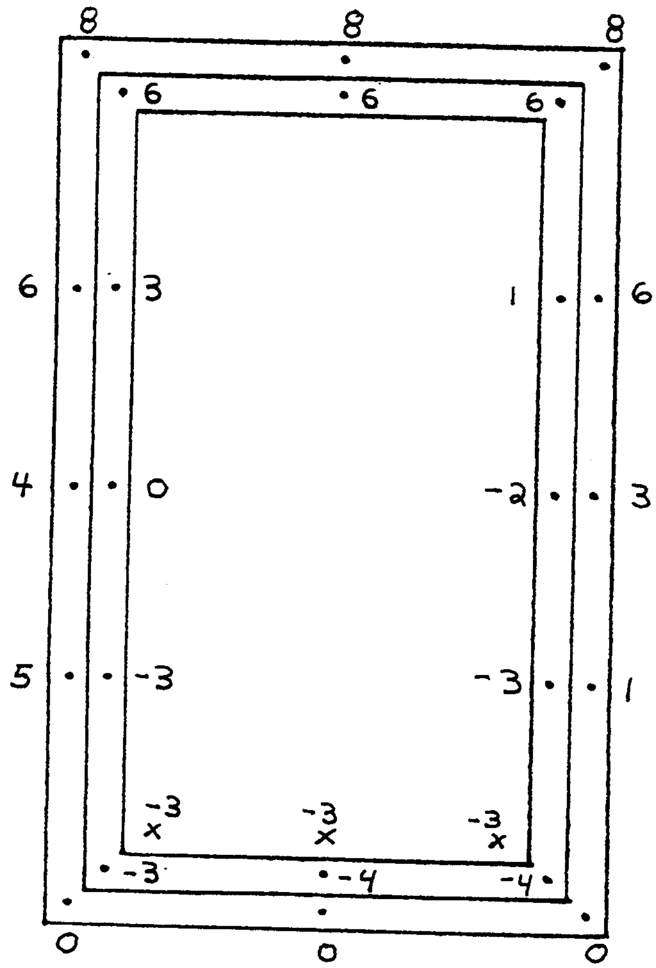
$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = -1
- Coldest frame temperature (Tf) = -2
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 29
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 28
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig= \frac{29}{50} \times 100$ = 58
- Temperature index for the frame $If= \frac{28}{50} \times 100$ = 56

The minimum acceptable value of I is 40

C33

PC-15 CYC: 2000



REMARQUES:

- Température de l'air sur le côté chaud de la fenêtre = 20 °C
- Température de l'air sur le côté froid de la fenêtre = -30 °C
- Epaisseur de la lame d'air =

AIR INS Inc.		
titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)	
dessiné par / dwg. by A.P.		feuille no. de / sheet no. of
vérifié par / chk. by A.P.		légende no. / mtl. list no.
échelle / scale	date	dessin no. / dwg. no.

C34

PC-15 CYC: 2000

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

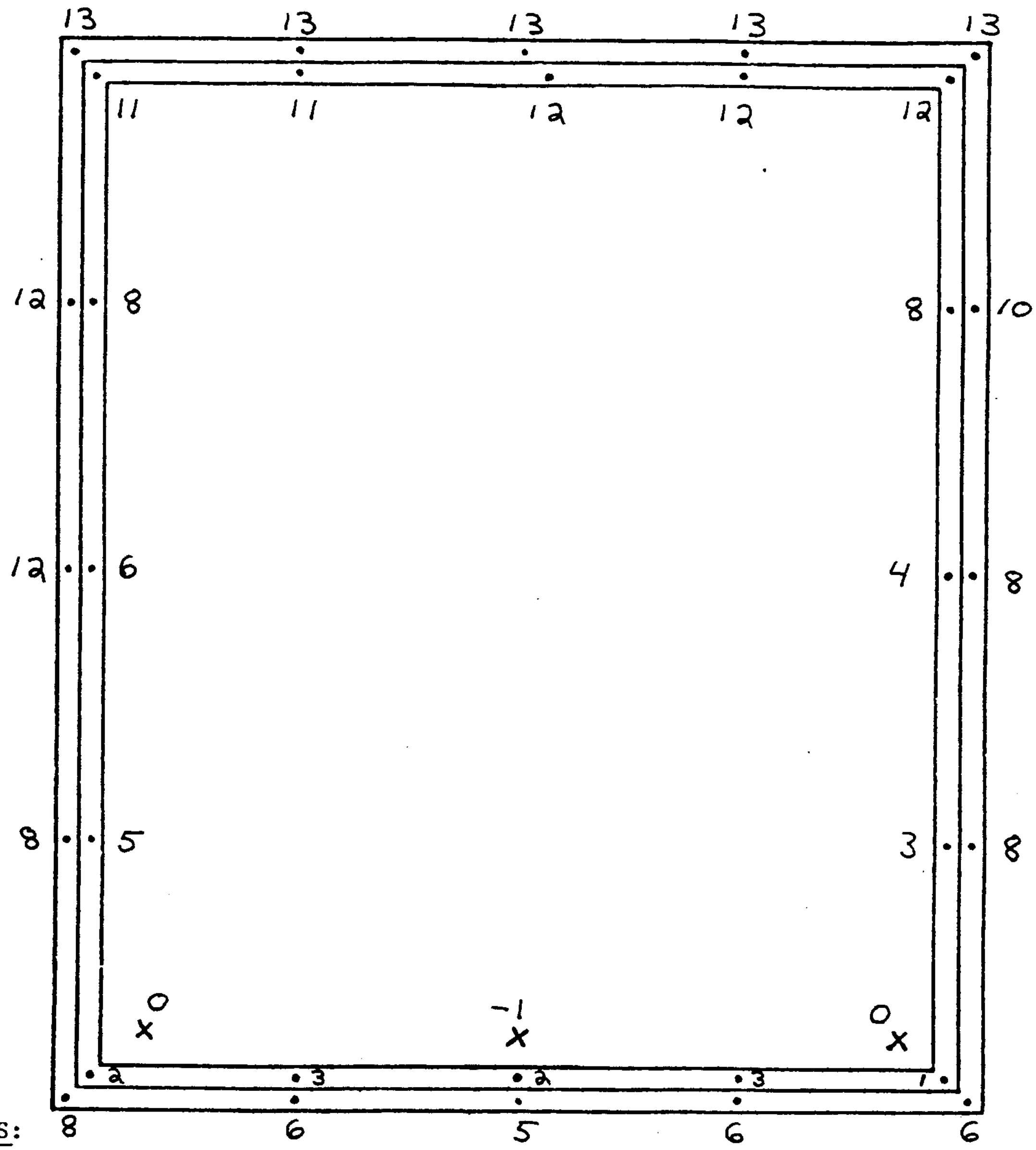
$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = -3
- Coldest frame temperature (Tf) = -4
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 27
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 26
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig = \frac{27}{50} \times 100$ = 54
- Temperature index for the frame $If = \frac{26}{50} \times 100$ = 52

The minimum acceptable value of I is 40

C35

PC-16 CYC: 2000



REMARQUES:

- Température de l'air sur le côté chaud de la fenêtre = 20 °C
- Température de l'air sur le côté froid de la fenêtre = -30 °C
- Epaisseur de la lame d'air =

AIR INS Inc.			
titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)		
dessiné par / dwg. by	A.P.	feuille no. de / sheet no. of	
vérifié par / chk. by	A.P.	légende no. / mtl. list no.	
échelle / scale	date	dessin no. / dwg. no.	

C36

PC-16 CYC: 2000

Determination of the "Temperature index" (I)

For the glass

$$I_g = \frac{T_g - T_c}{T_h - T_c} \times 100$$

For the frame

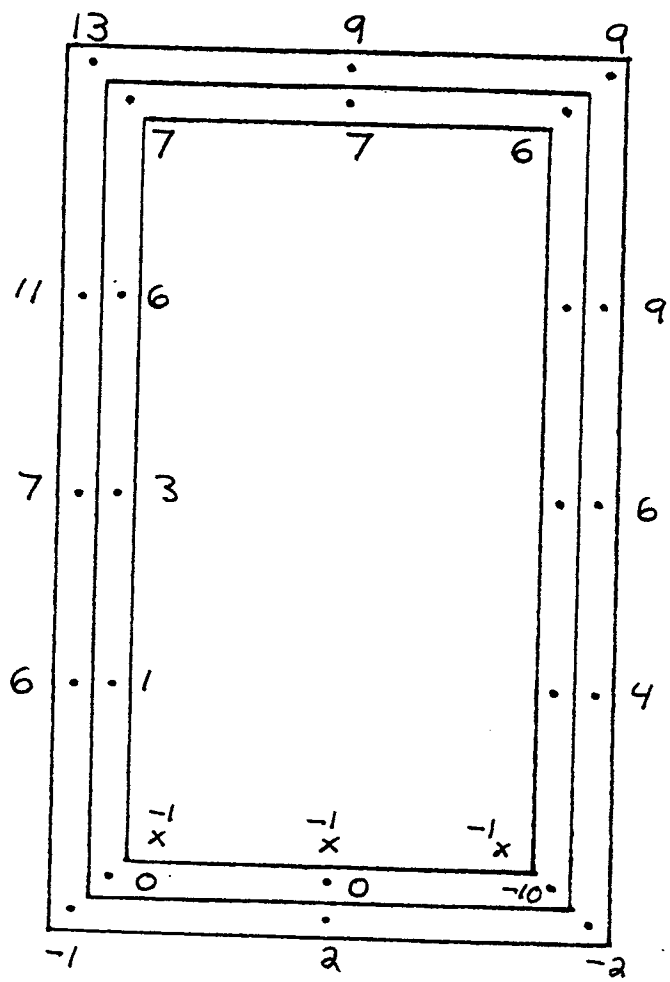
$$I_f = \frac{T_f - T_c}{T_h - T_c} \times 100$$

- Average surface temperature of glass (Tg) = 0
- Coldest frame temperature (Tf) = 1
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 30
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 29
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $I_g = \frac{30}{50} \times 100$ = 60
- Temperature index for the frame $I_f = \frac{29}{50} \times 100$ = 58

The minimum acceptable value of I is 40

C37

PC-17 CYC: 2000



REMARQUES:

- Température de l'air sur le côté chaud de la fenêtre = 20 °C
- Température de l'air sur le côté froid de la fenêtre = -30 °C
- Epaisseur de la lame d'air =

AIR INS Inc.		
titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)	
dessiné par / dwg. by	A.P.	feuille no. de / sheet no. of
vérifié par / chk. by	A.P.	légende no. / mtl. list no.
échelle / scale	date	dessin no. / dwg. no.

PC-17 CYC:2000

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

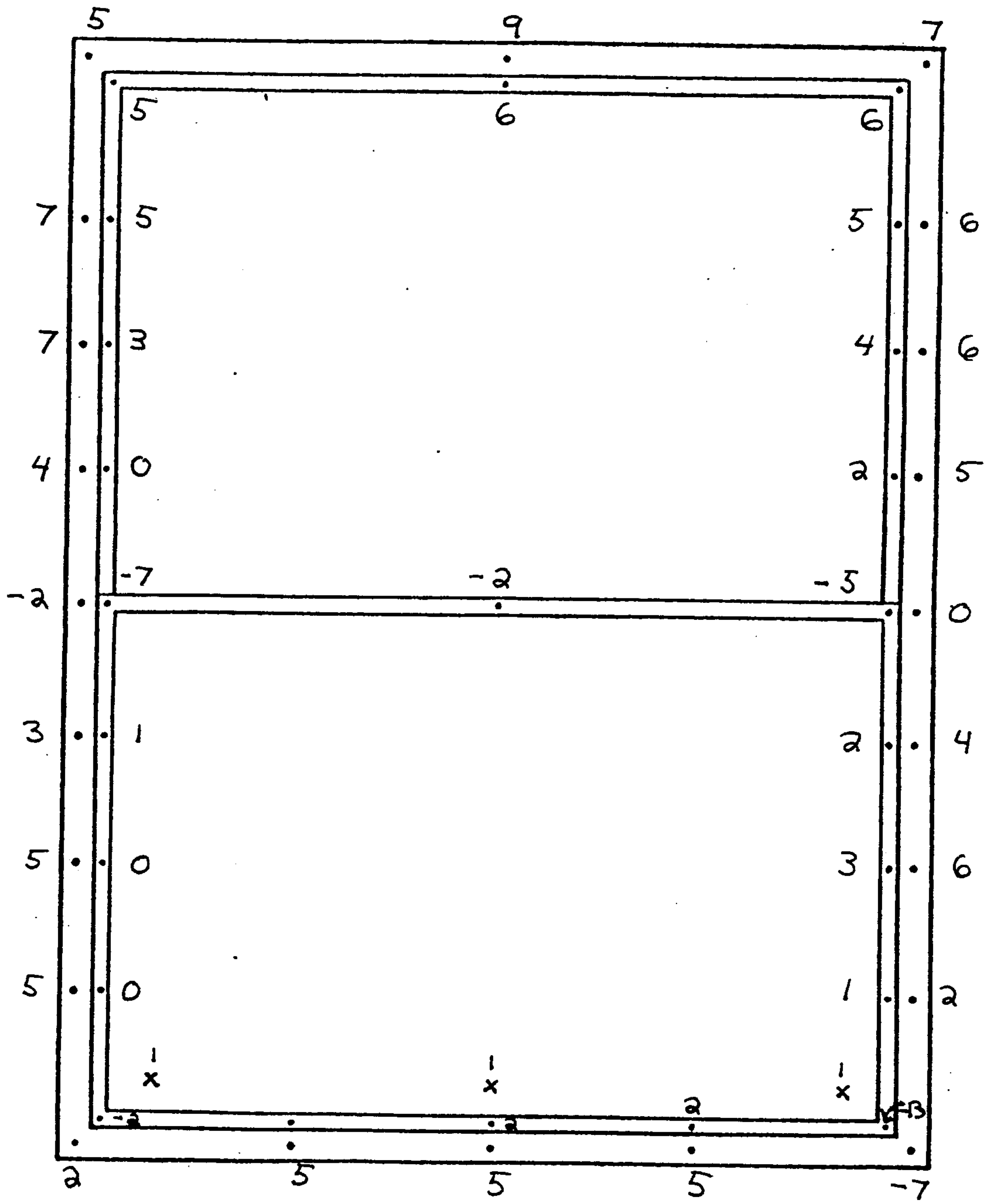
$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = -1
- Coldest frame temperature (Tf) = -10
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 29
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 20
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig = \frac{29}{50} \times 100$ = 58
- Temperature index for the frame $If = \frac{20}{50} \times 100$ = 40

The minimum acceptable value of I is 40

C39

PC-18 CYC: 2000



REMARQUES

- épaisseur de la lame d'air = ____ mm
- température de l'air sur le côté chaud de la fenêtre = 20 °C
- température de l'air sur le côté froid de la fenêtre = -30 °C

AIR INS Inc.		
titre / title	TEMPERATURE DE SURFACE (COTE CHAUD)	
dessiné par / dwg. by: A.P.	feuille no. de / sheet no. of	
vérifié par / chk. by: A.P.	légende no. / mtl. list no.	
échelle / scale	date	dessin no. / dwg. no.

C40

PC-18 CYC: 2000

Determination of the "Temperature index" (I)

For the glass

$$Ig = \frac{Tg - Tc}{Th - Tc} \times 100$$

For the frame

$$If = \frac{Tf - Tc}{Th - Tc} \times 100$$

- Average surface temperature of glass (Tg) = 1
- Coldest frame temperature (Tf) = -13
- Difference between the temperature (Tg) and the weather side temperature (Tc) = 29
- Difference between the temperature (Tf) and the weather side temperature (Tc) = 17
- Difference between the room-side temperature (Th) and the weather-side temperature (Tc) = 50
- Temperature index for the glass $Ig = \frac{29}{50} \times 100$ = 58
- Temperature index for the frame $If = \frac{17}{50} \times 100$ = 34

The minimum acceptable value of I is 40