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Publisher's version / Version de l'éditeur:

ASHRAE Transactions, 109, 1, pp. 600-606, 2003-05-01

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NRCC-45214

A version of this document is published in / Une version de ce document se trouve dans:
ASHRAE Transactions, v. 109, pt. 1, 2003, pp. 600-606

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ABSTRACT:

Windows are rated for their different performance parameters so that they could be evaluated either for adequacy to perform in specific applications, or to meet certain requirements. The rating of fenestration products also provides a means to compare products for selection purposes.

Test methods are already established to determine almost all the performance factors to assess window characterization in controlled environment. However, there is some disagreement about the testing protocol of windows for condensation resistance. There is a debate on whether windows should be tested with sealed or unsealed cracks.

This paper provides a discussion on how air leakage through the cracks can affect the test results when testing windows for condensation resistance. The intent is to determine the effects of the window design and the selection of components, such as weather-stripping, hardware and other components, on its condensation resistance. These effects would be masked when the cracks are sealed to prevent cold air from flowing through them, and hence changing the test results. This paper also provides test data to confirm the notion that when testing windows for condensation resistance, they should be tested without sealing any cracks in the assembly other than the interface between the window and the surround panel where it is installed.

KEY WORDS:

Window, Condensation; Rating; Air leakage; Temperature Index; Standard; Testing.

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INTRODUCTION:

Window manufacturers, specifiers, standards writing organizations and consumers are concerned about and demanding accurate, practical and reliable tools to assess the performance factors of fenestration products. There exists a number of national and international standards that address many of the product performance factors, which include: thermal transmission characteristics, water penetration, air leakage, structural strength, ease of operation, condensation resistance and others that are specific for certain products. Many of these standards specify the testing protocol and the procedure to determine the performance factor in question.

In Canada, CAN/CSA A440 Windows standard [1] includes a test procedure to determine the condensation resistance in a controlled laboratory setting. Provisions for determining the condensation resistance of some window types by means of computer simulation were proposed. However, sliding windows were excluded for the lack of solid technical data to support the prediction of the condensation resistance of such products. In particular, there was no consensus on the effects of air leakage on the condensation resistance that could be included in the computer analysis procedure for sliding windows. In addition, air leakage across the frame boundaries adds a new dimension in the calculation procedure, which has to deal with two-phase heat and mass transfer. A computer model for window heat transfer calculations, capable of analysing such complex phenomena, is not available at the present.

In an earlier study [2] it was shown that condensation resistance is affected by the air leakage characteristics of a number of window products. The study also indicated that further work is needed to arrive at a better understanding of the effect of air leakage on the window condensation resistance. In a recent study on the rating of condensation resistance of windows [3], a discussion comparing test results with computer calculation was presented. The authors concluded, based on a limited set of test results, that when testing windows with pressure balancing on both sides of the sample, no air leakage through the window takes place. This conclusion was not upheld in other test results carried out in this study as will be explained later. In reality, when the pressure is balanced in test chambers, there is localised air leakage through cracks as the air stream hits the window surface. Experimental data from tests carried out in this study will confirm this conclusion.

This work is aimed at providing technical information to show the impact of air leakage through the cracks on the condensation resistance through vertical sliding of windows. It is also aimed at providing guidance on how to quantify the effects of air leakage on the condensation resistance of windows through improving the testing protocol, and assists in planning further research work to address this issue in a detailed manner either by testing or by computer simulation.

Temperature Index:

Determining the product's Temperature Index (TI) assesses the condensation resistance of fenestration systems. TI is a non-dimensional parameter, which is defined as [4]:

$$TI = \frac{T_{sp} - T_c}{T_h - T_c} x100 \qquad (1)$$

where:

T_{sp}	specimen surface temperature, °C
T_c	weather (cold) side temperature, °C
T_h	warm (room) side temperature, °C

T_{sp} is measured at specific locations on the glass, frame and sash members of the product, as shown in Figure 1. T_h and T_c. are measured at the main stream on the warm and cold side of the test chamber, respectively. It is worth noting that there is a direct relation between TI and the condensation resistance; the higher the TI the higher the condensation resistance of windows.

T_h is maintained at 20±1°C, where as T_c is kept at -18±1°C. The film heat transfer coefficients were kept at 8±1 W/(m^2.K) on the warm side (natural convection) and at 30±2 W/(m^2.K) on the cold side. More details about the test procedure, sample mounting, data reduction and other specifics can be found in Reference 1. The TI is determined for the glazing, frame and sash members of the unit, and lowest value is used to "rate" the window for condensation resistance.

Tests were performed in the IRC guarded hot box (GHB) and in the air leakage test chamber. The uncertainty of measurements and the calibration of the GHB are explained in Reference 5.

Window Samples:

Three window samples were tested in this project:

1. A vinyl frame, vertical double hung sliding widow. This window will be referred to in the remainder of this paper as **VFW.**
2. A fibreglass, vertical sliding, double hung window. This window will be referred to in the remainder of this report as **FFW**.
3. An aluminium thermally broken, vertical double hung window. This window will be referred to in the remainder of this report as **AFW**.

Air Leakage:

All three windows were tested for air leakage according to CAN/CSA A440 testing protocol, i.e., at 75 Pa pressure differential, and ΔT=0 °C. Air leakage was determined under the following conditions:

a. all cracks were sealed on both sides (i.e., room side and weather side), Q1

b. all cracks were sealed on the room side only, Q2

c. all cracks were unsealed, Qs

d. all cracks were unsealed and the locks were unlocked, Q3

e. induced cracks by means of inserting a metal spacer of about 6-mm in diameter between the meeting rails, Q4.

In addition, windows were tested for air leakage at pressure differentials, higher than in the CAN/CSA A440 testing protocol (e.g., up to 300 Pa). This was done to determine their air leakage rate at higher pressure differentials across the windows to assess their air leakage characteristics.

Air Leakage Test Results:

For each test, the window is mounted in the surround panel and all cracks between the window frame and the surround panel are completely sealed. A heavy polyethylene sheet is used to cover the window, without overlap on the window/surround panel interface, to determine the extraneous air leakage of the entire system, Qe.

The extraneous air leakage was determined at three nominal different pressure differentials:75, 150 and 300 Pa. The actual pressure difference is shown in Table 1.

From Table 1, it is clear that the extraneous air leakage is extremely small and much lower than the allowable values as stated in the CAN/CSA A440 standard.

The air leakage of the three windows is determined according to the conditions described in items: a, b, c, d and e as above. Figures 2 to 6 demonstrate graphic representation of the windows air leakage at the above conditions. It should be noted that in the last set of air leakage tests (with induced air leakage), only the vinyl and fibreglass windows were tested.

Comments on the Air Leakage Test Results:

The following are some comments on the air leakage test results:

- The air leakage increased as the differential pressure across the window increases.
- The VFW and AFW windows did not meet the minimum requirement of A1 rating according to CAN/CSA A440 standard.
- The AFW window tested in this research work seems to experience the highest air leakage rate in all tests.
- The VFW and FFW windows have close air leakage rate when cracks on both sides of the window are sealed. However, the FFW window showed better air leakage performance when tested with unsealed cracks on both sides of the window. The same air leakage pattern of these two windows was noticed when tested with induced cracks using a metal spacer inserted at the meeting rails to increase the crack width. It seems that the weather-stripping on the FFW is performing well, and its rigid profiles contributed to the lower air leakage rate. Also, pressure balancing in the chamber may have contributed to this high air leakage performance.

By investigating the data in Figures 2 to 6, the window air leakage (at 75 Pa) increases by changing the location of the sealing (from room side to weather side), and also when the unit is sealed or not. For example, consider the air leakage rate at 75 Pa and the case when cracks on both sides are sealed as the base for comparison; see the data in Table 2. As the cracks were opened or induced, the air leakage rate for the VFW window increased from 0.001 to 0.0076 m^3/sec. For the FFW window, the increase is from 0.0008 to 0.0036 m^3/sec, and for the AFW window the increase is from 0.0031 to 0.0068 m^3/sec (this window was not tested with induced cracks).

On the other hand, if we consider the air leakage rate when all cracks are not sealed (Q_s) as the base for comparison, then as the cracks on the room side are sealed, the air leakage rate drops. For example, it dropped from 0.0048 to 0.0010 (79% reduction) for VFW window, from 0.0017 to 0.0008 (53% reduction) for the FFW window, from 0.0067 to 0.0031 (53% reduction) for the AFW window. However, when unlocking the locks on the windows, the trend is reversed. From Table 2, the increase in air leakage rate (when calculated based on Q_s) is about 19% for the VFW window, 0% for the FFW window and 1% for the AFW window.

Condensation Resistance (Temperature Index TI):

The condensation resistance (Temperature Index, TI) was determined for the three windows at the five air leakage conditions identified above (i.e., cracks sealed and unsealed, and also with induced air leakage). This test was performed with pressure balanced across the window sample during the test (i.e., $\Delta P \leq 10$ Pa) according to the test protocol in the CAN/CSA A440 standard. The parameter TI is determined by the expression in Equation 1.

Thermocouples were mounted on the glass, sash and frame members at the locations specified in the CAN/CSA A440 test method. For the glass, thermocouples were located at 50 mm from the sight line and at 50 mm/50 mm from the corners of the sash. In addition, extra thermocouples were located at 12.5 mm from the sight line at the centre of the glass and from the corners, for further analysis. See Figure 1 for details about the location of all thermocouple locations. Condensation resistance tests were performed on the three windows (except as noted below).

Comments on the Temperature Index Test Results:

For simplicity, the test results of TI are reported only at the points that are used in rating the windows for condensation resistance, i.e., points number 0, 1, 2, 8, 9 and 10, as shown in Figure 1. Table 3 provides the test data and TI of the three windows when tested at the different conditions with respect to cracks sealing or unsealing.

The following are some comments and observations on the temperature index behaviour:

1. It is obvious that when the cracks are sealed, cold air does not flow from the cold side to the warm side of the specimen. However, in the case of perpendicular airflow in the GHB, the impinging stream of cold air may result in cold air flowing through the cracks.

2. In case of pressure balancing in the GHB, air from the warm side of the GHB tends to flow through the cracks and raises the glass temperature in the vicinity of the cracks.

3. In both cases above, false thermocouple readings may be observed, and hence wrong TI results. This is illustrated in the comments below, which examine the calculated TI of the three samples tested.

4. For the VFW window, TI increases at points 0, 1, 2, 3 and 10 from the case when all cracks were sealed to no sealing of cracks. At the same time, when cracks are induced, considerable reduction in TI was observed at points 8, 9 and 10.

5. A reverse trend is observed when examining test results of the FFW window. See Table 3 for the surface temperatures and TI at the selected points on the glass and frame. It is possible that this reverse trend is due to the shape of the window profile as it affects the direction of cold airflow around the sash.

6. The TI of the FFW window seems to increase slightly (relative to that when cracks are sealed) when the locks were open and no sealing of cracks was applied. In Table 3, the TI values increased when cracks were induced by means of a metal spacer, relative to those values when cracks were sealed. This can only be explained as follows: as cracks are opened and a localised negative pressure across the window exists (higher local pressure at the room side), warm air flows from the room side to the weather side causing the glass and sash surface temperature to rise, hence increasing the TI values.

7. In case of the AFW window, TI did not change as a result of sealing or unsealing of the cracks. See Table 3 below. This window was not tested with induced cracks or with unlocked locks.

8. All air leakage test results indicate that all the windows experience air leakage at different rates. This may lead to the conclusion that the Temperature Index of these windows changes as a result of cold or warm air flowing through the cracks. The final effect would depend on which cracks are sealed and which are not sealed. Also, it would depend on the direction of airflow (infiltration or exfiltration). Nevertheless, TI will not be the same when determined at different conditions of cracks sealing.

9. The fact that TI increased or decreased in a non-predictable manner shows that the test procedure should be revised to reflect the cases where infiltration or exfiltration can be controlled. In other words, the pressure should not be balanced across the sample in order to ensure control over the direction of airflow through the cracks.

The results shown above indicate that the air leakage has a considerable impact on the Temperature Index, hence the condensation resistance rating of window products. The fact that during testing, the pressure is balanced (globally) on both sides of the window, it creates a condition where air does not flow through the cracks as it usually does in a window installed in a building façade. During the heating season, cold air will flow through the cracks, but depending on the location of the window in the building envelope, and on the size of the cracks.

The assessment of the condensation resistance of window products by means of TI (particularly for rating purposes) should be performed in such a way to differentiate between poorly designed and well-constructed windows. By sealing the cracks around the sash and frame members, most of the defects in the window construction are masked and become hidden behind the tape. This results in arriving at a somewhat inaccurate assessment of the condensation resistance of the product. The final results are not beneficial to window manufacturers or consumers.

The intent is to perform additional testing on other window types to investigate this matter further, and mainly to review the condensation test procedure in the CAN/CSA A440 standard in order to arrive at a more accurate and equitable procedure in determining the correct condensation resistance rating of windows.

CLOSING REMARKS:

The air leakage of the three windows tested in this project increased as the pressure differential across the window increases. The VFW and AFW windows experienced higher than usual airflow rate (they were below the minimum air leakage rate A1), and the FFW window is rated at A2.

As the cracks on either side of the windows were sealed, the air leakage rate decreased for all windows. On the other hand, when cracks were induced by means of a metal spacer at the meeting rails to increase the crack width, the air leakage rate significantly increased. This is done to emphasise that the size of the cracks affects the air leakage rate of the window.

The Temperature Index of windows is affected by the state of the cracks whether sealed or unsealed. The degree of change depends on how accurately the test is conducted, the sash and frame profile and the presence of localised pressure differential across the cracks.

The three window tested in this report were rated very low for air leakage, therefore, it is expected that the TI would be substantially lower when cracks are unsealed. However, due to the flow of air from the warm side through the cracks, the glass surface temperature increases (in some cases) resulting in unexpected increase in TI.

It is recommended that tests should be conducted with a positive pressure differential (of the order of 15 Pa higher on the weather side) to simulate air infiltration during a winter day. Conducting the test under this condition will ensure that warm air does not flow from the warm side to the cold side during the test, which is contrary to the real situation of air infiltration. Also, it would be advantageous to perform the tests under exfiltration, where the pressure would be higher on the room side than that on the weather side.

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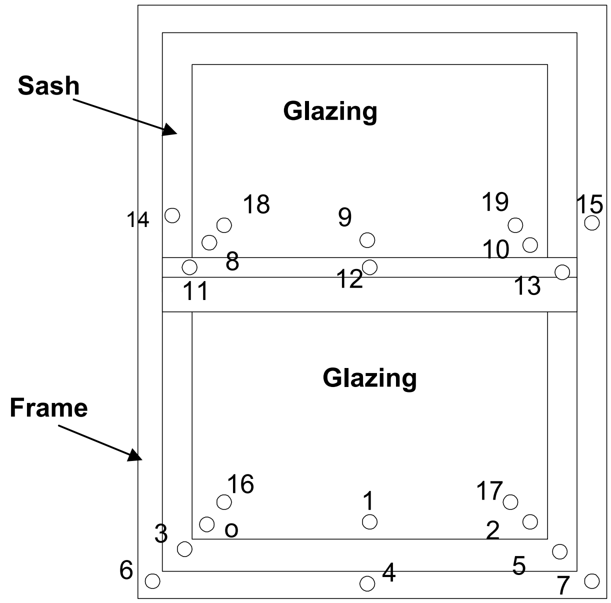

FIGURE 1

A schematic diagram showing the location of thermocouples on the window surfaces

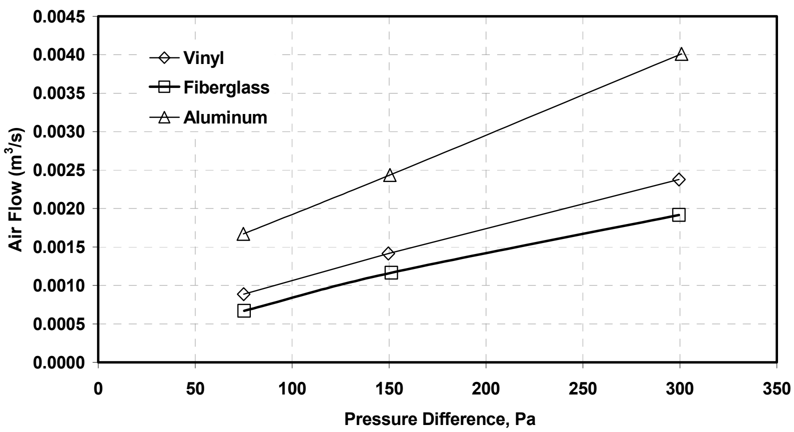

FIGURE 2
Window air leakage with both sides sealed, Q_1

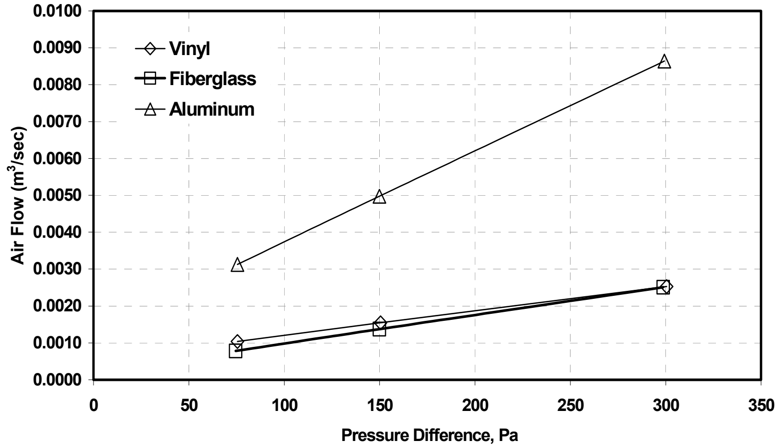

FIGURE 3
Window air leakage with room-side sealed, Q_2

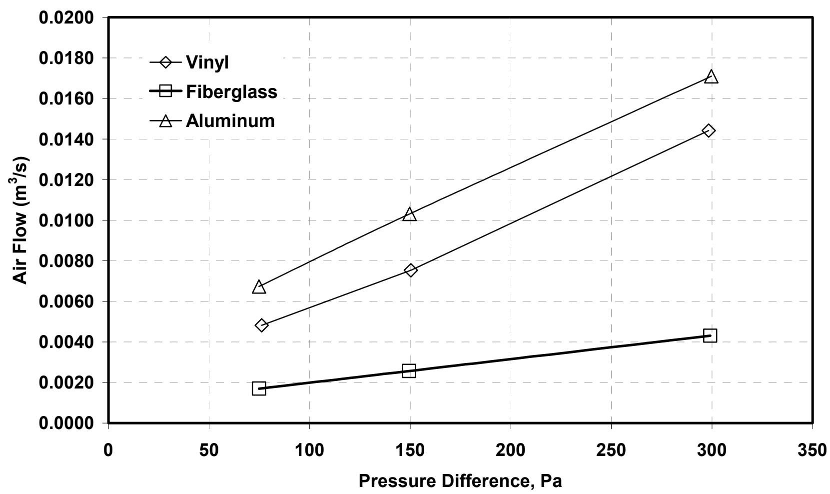

FIGURE 4

Window Air Leakage with no sealing of cracks on both sides, Q_s

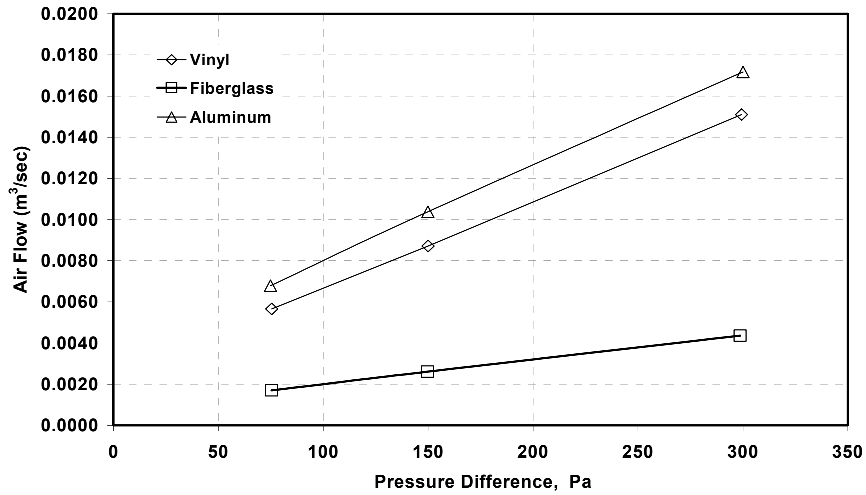

FIGURE 5

Window Air Leakage with Locks Unlocked, and Cracks Unsealed, Q_3

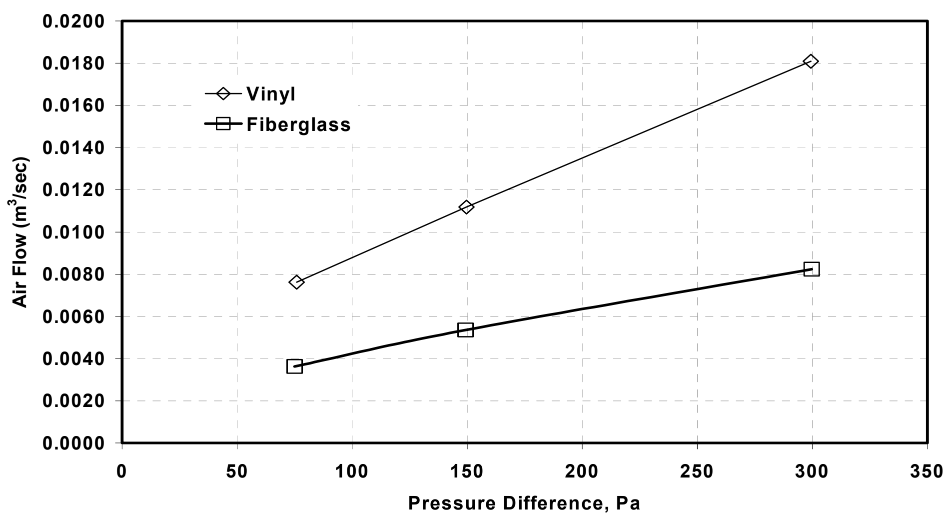

FIGURE 6

Window Air Leakage with Induced Leakage using a Metal Spacer, Q_4

TABLE 1

Comparison of Extraneous Air Leakage for VFW, FFW, and AFW Windows

Window Specimen	Type of test Extraneous Air leakage, Qe	Approximate □p	Average Leakage
		(Pa)	(m^3/s)
VFW	Qe	76	0.0001
VFW	Qe	150	0.0001
VFW	Qe	300	0.0002
FFW	Qe	76	0.0001
FFW	Qe	150	0.0001
FFW	Qe	300	0.0002
AFW	Qe	76	0.0001
AFW	Qe	151	0.0002
AFW	Qe	301	0.0003

TABLE 2

Comparison of the increase in air leakage rate with crack opening

Widow	Base air leakage rate, cracks are sealed on both sides, Q_1	Air leakage, cracks on room side are sealed, Q_2 (%age increase)	Air leakage, cracks on both sides are not sealed, Q_s, (% increase)	Air leakage, cracks are not sealed, locks are not locked, Q_3 (%age increase)	Air leakage, induced cracks with a metal spacer, Q_4 (%age increase)
VFW	0.0009	0.0010 **(11%)**	0.0048 **(433%)**	0.0057 **(533%)**	0.0076 **(744%)**
FFW	0.0007	0.0008 **(14%)**	0.0017 **(143%)**	0.0017 **(143%)**	0.0036 **(414%)**
AFW	0.0017	0.0031 **(82%)**	0.0067 **(294%)**	0.0068 **(300%)**	N/A

TABLE 3

Surface Temperature and Temperature Index for the Three Windows

Surface temperature and TI of the VFW window										
Point No.	Sealed on both sides		Sealed on room side		No sides sealed		Locks open		Induced cracks	
	°C	TI	°C	TI	°C	TI	°C	TI	°C	TI
	Test 1	%	Test 2	%	Test 3	%	Test 4	%	Test 5	
0	1.98	53	2.45	55	4.47	60	4.47	60	3.91	58
1	0.72	50	1.34	52	2.4	54	2.4	54	2.27	54
2	0.44	49	0.75	51	1.44	52	1.44	52	1.26	51
8	-1.76	43	0.41	50	-1.91	43	-1.91	43	-3.08	40
9	-1.78	43	0.80	51	-1.91	43	-1.91	43	-4.2	37
10	-2.25	42	-1.73	44	-1.91	43	-1.91	43	-3.34	39
Surface temperature and TI of the FFW window										
	Test 7	%	Test 8	%	Test 9	%	Test 10	%	Test 11	%
0	0.49	49	-0.1	48	-0.15	47	2.01	53	2.6	55
1	0.33	49	-0.1	48	-0.21	47	0.88	50	1.57	52
2	0.64	50	-0.18	47	-0.08	48	0.51	49	1.01	51
8	-2.07	42	-2.33	42	-1.89	43	-2.04	43	-1.29	45
9	-1.86	43	-2.07	42	-1.99	43	-2.12	42	-2.12	42
10	-2.8	41	-3.19	40	-2.9	40	-3.11	40	-2.46	42
Surface temperature and TI of the AFW window										
	Test 13	%	Test 14	%	Test 15	%				
0	2.91	56	2.70	55	3.47	56				
1	1.93	54	2.04	54	2.55	54				
2	1.93	54	1.93	53	2.50	54				
8	-0.93	46	-0.85	46	-0.39	46				
9	-1.21	46	-0.96	46	-0.39	46				
10	-1.14	46	-1.01	45	-0.39	46				