CONDENSATION RESISTANCE LITERATURE REVIEW AND MANUFACTURER SURVEY

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Executive Summary

Improved condensation resistance is one of the non-energy benefits of high-performance windows. The CSA test for condensation resistance is now optional and consequently, for cost reasons, not used by many manufacturers, in spite of the fact that moisture problems occasionally result in call backs. This study reviews products that have been rated, includes measurements made as a result of other CANMET research, and summarizes comments from interviews with several manufacturers. Finally the latest VISION and FRAME programs are used to simulate the Temperature Index for a fixed window with various glazing and spacer options. Conclusions reflect the reality of the marketplace but also the benefits of high-performance windows in terms of condensation resistance.

Résumé

Une résistance accrue de la condensation est l'un des bénéfices des fenêtres à haut rendement ne relevant pas de l'efficacité énergétique. La méthode de test de la norme de l'Association canadienne de normalisation (CSA) est actuellement optionelle et, pour des raisons de coût, n'est pas utilisée par plusieurs manufacturiers en dépit du fait que les problèmes de condensation nécessite occasionnellement un rappel du manufacturier. Cette étude comprend une révision des produits déjà évalués, à laquelle se rajoutent les données recueillies lors d'autres projets de recherche de CANMET, et un sommaire des résultats d'entrevues avec divers manufacturiers. Une évaluation de la gamme d'indices de température d'une fenêtre fixe a aussi été menée par modélisation sur ordinateur, en utilisant les logiciels FRAME et VISION, en variant le type de vitrage et d'intercalaire. Les conclusions de cette étude permettent d'apprécier la réalité du marché de même que les avantages des fenêtres à haut rendement en ce qui concerne la résistance à la condensation.

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1.0 Introduction

The issue of condensation forming on windows is of great concern to home owners. Condensation can lead to structural damage of the window and the surrounding wall, as well as mould growth and the related health problems. In 1984 the Canadian Standards Association first introduced a test procedure to rate windows for condensation resistance. The 1984 standard required testing for condensation resistance for all metal windows, including thermally-broken and any non-thermally-broken metal products. Testing was optional for wood and vinyl windows. In 1990, the condensation resistance test procedure was revised and the standard updated. The 1990 standard made condensation resistance testing optional for all window types. The result of the change to the standard is that very few windows have been tested for condensation resistance.

The lack of condensation resistance testing by window manufacturers needed to be studied. This research project includes three phases to study the issues of condensation resistance testing in the window industry. The first phase of the project involves a literature review to determine what data is available on condensation resistance for windows available in Canada. The second phase of the project is to conduct a survey of window manufacturers to get their opinion on condensation as an issue in the window industry. The final phase of this project includes the computer simulation of a simple fixed window to predict the condensation resistance of the window and model several upgrades to the window and evaluate the improvement in resistance to condensation for the upgrades. The results of the three phases of this research project are presented as well as conclusions drawn from this work.

2.0 Condensation Literature Review

Several window manufacturers were contacted to discuss condensation resistance. Only two of the window manufacturers contacted had tested for condensation resistance and their results are available in the Canadian Window and Door Manufacturers Association (CWDMA) Certified Products List (CWDMA 1996). Two commercial testing laboratories were contacted to discuss sources of condensation resistance test data. The laboratories identified two sources of test data. The first source was a round robin testing project conducted by the National Research Council (NRC) in the late 1980's (NRC 1990). The second source was a research project conducted by Air-Ins, "Study of the Long Term Performance of Operating and Fixed Windows Subjected to Pressure Cycling" (Air-Ins, 1991). This project measured several physical properties of ten window systems, including the condensation resistance, and then subjected the windows to pressure cycling and measured the physical properties again. The Air-Ins study reports the Temperature Index (condensation resistance rating) for the window initially and after 2000 pressure cycles.

The NRC round robin research project used seven windows that were tested for condensation resistance and Temperature Index (TI) values were determined according to the CSA A440-M90 condensation resistance procedure (CSA 1990). Four of the windows were tested by four different laboratories. The test results for the round robin are included in Table 1. All of the

Table 1 NRC Round Robin Testing in 1990

Reference Number	Window Number	Window Type	Frame Description	Glass Description	Laboratory			
					1	2	3	4
W-1	1	Vertical Slider	Aluminum frame with thermal-break	Clear-Air-Clear	54	54	49	52
W-2	2	Casement	Aluminum frame with thermal-break	Clear-Air-Clear	57	54	56	53
W-3	3	Horizontal Slider	Aluminum frame with thermal-break	Clear-Air-Clear	57	53	51	51
W-4	4	Fixed	Aluminum frame with thermal-break	Clear-Air-Clear	59	52	--	52
W-5	5	Horizontal Slider	Wood with vinyl cladding	Clear-Air-Clear	--	--	--	45
W-6	6	Casement	Wood with aluminum cladding	Clear-Air-Clear	--	--	--	53
W-7	7	Casement	Wood with aluminum cladding	Clear-Air-Clear-Air-Low-E	--	--	--	59

windows tested were of different material and operator types. It is difficult to compare the TI values for these windows because of the different material and operator types. Windows W-1 to W-4 were different operator types, but all had thermally-broken aluminum frames with the same insulating glass unit. The NRC (laboratory 4) TI values for these windows range from 51 to 53. This shows very good agreement for TI results from the same laboratory. The TI values for windows W-1 to W-4 from all four of the laboratories range from 49 to 59. The wide range in the results from the different laboratories indicates that there must be differences in how the laboratories are testing the windows.

The Air-Ins research project included ten window systems with varying frame materials and operator types. The Air-Ins research project results are included in Table 2. All the windows in the Air-Ins study used the same double glazed clear glass unit with an aluminum spacer. The Air-Ins study reported initial TI values for both the glass and the frame. The initial glass TI values ranged from 56 to 62, which looks reasonable considering the glass units are all in different frame types. The wood window frame TI values ranged from 32 to 58. The PVC window frame TI values ranged from 10 to 58. The results after 2000 pressure cycles show significant reductions in the frame TI values. The results of the pressure cycling are discussed at length in the Air-Ins report. This study is comparing initial TI values, the values after 2000

Table 2 Air-Ins Motion and Pressure Cycling Study

Reference Number	Window Number	Window Type	Frame Description	Glass Description	Initial		2000 Cycles	
					TI_G	TI_F	TI_G	TI_F
W-8	PC-1	Vertical Slider	Aluminum	Clear-Air-Clear	62	50	60	40
W-9	PC-8	Horizontal Slider	PVC	Clear-Air-Clear	60	40	58	40
W-10	PC-9	Casement	PVC	Clear-Air-Clear	60	52	54	22
W-11	PC-10	Casement	PVC	Clear-Air-Clear	60	18	54	16
W-12	PC-11	Vertical Slider	PVC	Clear-Air-Clear	60	10	56	12
W-13	PC-13	Fixed	PVC	Clear-Air-Clear	58	58	58	56
W-14	PC-15	Casement	Wood	Clear-Air-Clear	58	48	54	52
W-15	PC-16	Fixed	Wood	Clear-Air-Clear	56	58	60	58
W-16	PC-17	Casement	Wood	Clear-Air-Clear	60	38	58	40
W-17	PC-18	Vertical Slider	Wood	Clear-Air-Clear	60	32	58	34

cycles will not be discussed further here. The wide range in the frame TI values for a given frame material can be partially attributed to the operator type, vertical sliders tend to have higher air leakage and could reduce frame temperatures, but the range of 18 to 52 on a PVC casement window may indicate problems in construction of the windows. These results do indicate that there can be a very large variation of TI values for windows of the same material type and operator type.

The CWDMA Certified Products List has two manufacturers listed that have tested for condensation resistance. The CWDMA results are included in Table 3. One of the manufacturers lists six PVC windows of different operator types. The six windows all have the same high performance insulating glass unit construction. The TI values for these six windows range from 61 to 66. The use of the high performance glass unit which includes a low-e coating, argon gas fill, and a warm edge foam spacer results in high TI values. The second manufacturer has included 22 thermally-broken aluminum window products in the list of different operator types. Eighteen of the windows have either sealed double glazed insulating glass units or unsealed double glazed systems. The 18 double glazed systems have TI values that range from 45 to 58. The product with the TI of 45 also has a high level of air infiltration. The remaining 17 products range from 54 to 58. The other four products listed either have a double glazed IG unit with a low-e coating and argon gas fill, or have a double glazed standard IG unit with a storm panel. These four products range in TI value from 64 to 66. These results indicate consistent TI values for similar products. Each of these manufacturers has probably used the same testing laboratory and the products would all be of similar construction quality, resulting in the consistent TI values.

Table 4 includes the TI values for all 45 windows found in this literature review. The data has been sorted based on frame material type, number of glass layers, low-e coating or not, gas fill or not, and spacer type. The sorting of the data results in six sets of data, with more than two data points, of similar construction. Four of the data sets show wide ranges of TI values for windows that are very similar in construction. Some of this discrepancy could be accounted for based on the different operator types, because some of the windows may have higher air leakage than others. Some of the discrepancy can also be accounted for because the data is coming from several laboratories. The NRC study indicated that there can be a large variation in TI value from one laboratory to another.

Table 3 CWDMA Certified Products List

Reference Number	Manufacturer	Window Type	Frame Type	ER	A	B	C	I	Low-E	Gas	Spacer	Glass
W-18	Centennial	Horizontal Slider	PVC	-3	A2	B2	C3	66	Yes	Argon	ZF	2
W-19	Centennial	Fixed	PVC	7	FX	B7	C3	64	Yes	Argon	ZF	2
W-20	Centennial	Fixed	PVC	0	FX	B7	C4	64	Yes	Argon	ZF	2
W-21	Centennial	Casement	PVC	-3	A3	B5	C3	61	Yes	Argon	ZF	2
W-22	Centennial	Awning	PVC	-2	A3	B7	C4	65	Yes	Argon	ZF	2
W-23	Centennial	Vertical Slider	PVC	-2	A2	B3	C3	62	Yes	Argon	ZF	2
W-24	Gentek (Alcan)	Fixed	T/B Aluminum	-17	FX	B7	C5	54	x	Air	A5	2
W-25	Gentek (Alcan)	Fixed	T/B Aluminum	-16	FX	B7	C5	54	x	Air	A5	2
W-26	Gentek (Alcan)	Fixed	T/B Aluminum	-16	FX	B7	C5	58	x	Air	A5	2
W-27	Gentek (Alcan)	Fixed	T/B Aluminum	0	FX	B7	C5	64	Yes	Argon	A5	2
W-28	Gentek (Alcan)	Horizontal Slider	T/B Aluminum	-20	A3	B7	C4	54	x	Air	x	1+1
W-29	Gentek (Alcan)	Horizontal Slider	T/B Aluminum	-20	A3	B7	C4	54	x	Air	x	1+1
W-30	Gentek (Alcan)	Horizontal Slider	T/B Aluminum	-20	A3	B7	C4	54	x	Air	x	1+1
W-31	Gentek (Alcan)	Horizontal Slider	T/B Aluminum	-20	A3	B7	C4	54	x	Air	x	1+1
W-32	Gentek (Alcan)	Horizontal Slider	T/B Aluminum	-20	A3	B7	C4	54	x	Air	x	1+1
W-33	Gentek (Alcan)	Horizontal Slider	T/B Aluminum	-20	A3	B7	C4	54	x	Air	x	1+1
W-34	Gentek (Alcan)	Horizontal Slider	T/B Aluminum	-15	A3	B7	C4	56	x	Air	x	1+1
W-35	Gentek (Alcan)	Horizontal Slider	T/B Aluminum	-15	A3	B7	C4	56	x	Air	x	1+1
W-36	Gentek (Alcan)	Horizontal Slider	T/B Aluminum	-15	A3	B7	C4	56	x	Air	x	1+1
W-37	Gentek (Alcan)	Horizontal Slider	T/B Aluminum	-8	A3	B7	C4	65	x	Air	A5	2+1
W-38	Gentek (Alcan)	Horizontal Slider	T/B Aluminum	-10	A3	B7	C4	56	x	Air	x	1+1
W-39	Gentek (Alcan)	Horizontal Slider	T/B Aluminum	-10	A3	B7	C4	56	x	Air	x	1+1
W-40	Gentek (Alcan)	Horizontal Slider	T/B Aluminum	-10	A3	B7	C4	56	x	Air	x	1+1
W-41	Gentek (Alcan)	Horizontal Slider	T/B Aluminum	-3	A3	B7	C4	66	x	Air	A5	2+1
W-42	Gentek (Alcan)	Casement	T/B Aluminum	-14	A3	B7	C5	65	Yes	Argon	A5	2
W-43	Gentek (Alcan)	Casement	T/B Aluminum	-25	A3	B7	C5	56	x	Air	A5	2
W-44	Gentek (Alcan)	Awning	T/B Aluminum	-22	A3	B7	C5	57	x	Air	A5	2
W-45	Gentek (Alcan)	Vertical Slider	T/B Aluminum	-28	A2	B3	C3	45	x	Air	A5	2

Table 4 Complete set of Condensation Resistance Data from Literature Review

Reference Number	Frame Material	Number of Glass Layers	Low-e Coating	Gas Fill	Spacer Type	Operator Type	Temperature Index	Data Source
W-1	AT	2	N	Air	A1	VS	52	NRC
W-2	AT	2	N	Air	A1	CA	53	NRC
W-4	AT	2	N	Air	A1	FX	52	NRC
W-8	AT	2	N	Air	A1	VS	40	Air-Ins
W-24	AT	2	N	Air	A5	FX	54	CWDMA2
W-25	AT	2	N	Air	A5	FX	54	CWDMA2
W-26	AT	2	N	Air	A5	FX	58	CWDMA2
W-43	AT	2	N	Air	A5	CA	56	CWDMA2
W-44	AT	2	N	Air	A5	AW	57	CWDMA2
W-45	AT	2	N	Air	A5	VS	45	CWDMA2
W-27	AT	2	Y	Argon	A5	FX	64	CWDMA2
W-42	AT	2	Y	Argon	A5	CA	65	CWDMA2
W-3	AT	1+1	N	Air	x	HS	51	NRC
W-28	AT	1+1	N	Air	x	HS	54	CWDMA2
W-29	AT	1+1	N	Air	x	HS	54	CWDMA2
W-30	AT	1+1	N	Air	x	HS	54	CWDMA2
W-31	AT	1+1	N	Air	x	HS	54	CWDMA2
W-32	AT	1+1	N	Air	x	HS	54	CWDMA2
W-33	AT	1+1	N	Air	x	HS	54	CWDMA2
W-34	AT	1+1	N	Air	x	HS	56	CWDMA2
W-35	AT	1+1	N	Air	x	HS	56	CWDMA2
W-36	AT	1+1	N	Air	x	HS	56	CWDMA2
W-38	AT	1+1	N	Air	x	HS	56	CWDMA2
W-39	AT	1+1	N	Air	x	HS	56	CWDMA2
W-40	AT	1+1	N	Air	x	HS	56	CWDMA2
W-37	AT	2+1	N	Air	A5	HS	65	CWDMA2
W-41	AT	2+1	N	Air	A5	HS	66	CWDMA2
W-6	AW	2	N	Air	A1	CA	53	NRC
W-7	AW	3	Y	Air	A1	CA	59	NRC
W-5	VW	2	N	Air	A1	HS	45	NRC
W-9	VY	2	N	Air	A1	HS	40	Air-Ins
W-10	VY	2	N	Air	A1	CA	22	Air-Ins
W-11	VY	2	N	Air	A1	CA	16	Air-Ins
W-12	VY	2	N	Air	A1	VS	12	Air-Ins
W-13	VY	2	N	Air	A1	FX	56	Air-Ins
W-18	VY	2	Y	Argon	ZF	HS	66	CWDMA1
W-19	VY	2	Y	Argon	ZF	FX	64	CWDMA1
W-20	VY	2	Y	Argon	ZF	FX	64	CWDMA1
W-21	VY	2	Y	Argon	ZF	CA	61	CWDMA1
W-22	VY	2	Y	Argon	ZF	AW	65	CWDMA1
W-23	VY	2	Y	Argon	ZF	VS	62	CWDMA1
W-14	WD	2	N	Air	A1	CA	52	Air-Ins
W-15	WD	2	N	Air	A1	FX	58	Air-Ins
W-16	WD	2	N	Air	A1	CA	40	Air-Ins
W-17	WD	2	N	Air	A1	VS	34	Air-Ins

3.0 Survey of Window Manufacturers

Seven window manufacturers were surveyed to get their opinions on condensation on windows. Ten questions were prepared to ask each of the manufacturers (a copy of the questionnaire is included in Appendix A). The manufacturers surveyed included one manufacturer from Atlantic Canada, one from Quebec, three from Ontario, one from Manitoba and one from British Columbia. The manufacturers also varied in the types of materials they build their windows from, one manufacturer builds only thermally-broken aluminum windows, two manufacturers build wood and vinyl windows, one manufacturer builds wood and aluminum-clad wood windows, one manufacturer builds fibreglass and vinyl windows and one manufacturer builds thermally-broken aluminum and vinyl windows.

When asked as to how condensation affects their business, the repeated response from the manufacturers surveyed was that the main concern about condensation is the number of call backs they receive as a result of condensation problems. The manufacturers all reported that their number of call backs have decreased greatly over the past few years. The decrease in call backs is attributed to the addition of a warm edge spacer option in all of the manufacturers products. Three of the seven manufacturers only offer a warm edge spacer in their products. These manufacturers had changed over from metal spacer bar and the primary reason for the change was to reduce condensation problems. These manufacturers report a dramatic reduction in the number of call backs for condensation problems and attribute the reduction to the use of a warm edge spacer in all their products.

When questioned if the manufacturers had ever tested for condensation resistance under CSA A440 to determine a Temperature Index (TI), only three of the manufacturers had. Two of these manufacturers offered thermally-broken aluminum windows and had tested their products when testing of aluminum products was required under CSA A440-M84. They have continued to test some of their products to CSA A440-M90 even though the testing is no longer required, because the TI is still requested on thermally-broken aluminum windows for some projects. The third manufacturer has tested their PVC windows for condensation resistance for marketing reasons and uses the data to promote their products. The other manufacturers saw little value in testing for TI. One manufacturer stated that for wood and vinyl windows condensation is an issue on the glass and not the frame, and they have addressed the problem by adding a warm edge spacer. Another manufacturer stated that the TI is not a very good indicator of condensation resistance on the glass, because the glass temperature is not measured close enough to the edge-of-glass.

The manufacturers were asked if they felt that including condensation resistance in the window certification program was important. One of the manufacturers uses the Temperature Index results to promote their products and believes the certification program adds credibility to the Temperature Index values. The other manufacturers felt that there was very little value in the Temperature Index. Manufacturers that supply windows for new construction explained that condensation resistance is of little interest to the builder buying the windows. All but one of the manufacturers that supply windows into the renovation market felt that they can not use the Temperature Index number very effectively because it is difficult to explain to consumers.

The window manufacturers were asked what kind of feedback they get from consumers regarding condensation. All of the manufacturers reported very small numbers of call backs as a result of condensation problems. The manufacturers were also asked what do they tell consumers about condensation. Several of the manufacturers have literature they send out to consumers to try and explain the condensation problem and this is the first attempt they make to educate the consumer. If the information does not help the consumer reduce the condensation problem, some of the manufacturers send someone to the consumers home to assess the problem. The first thing the manufacturers all did was to get an indication of the environmental conditions in the home. The root of almost all the severe problems was very high humidity levels in the homes. The manufacturers would work with the consumer to determine the cause of the high humidity levels. Some of the causes of the high humidity that they described include: dryer vents that were not connected and venting into the house, clothing being hung inside the home to dry, and the lack of exhaust fans in bathrooms. Several of the manufacturers that supply the renovation market also commented on the situation where the installation of new windows tightens up the building envelope and traps the moisture in the house. Now with the new "better" windows the home owner has a condensation problem.

The manufacturers were asked if they felt that air leakage affected condensation. They all agreed that condensation due to air infiltration is a symptom of the air leakage problem. Several of the manufacturers did comment on the situation where under extreme temperature differentials the bowing of the framing members of some vinyl windows will lead to increased air leakage. They also pointed out that in certain situations this air leakage would lead to condensation and in other situations the cold dry air coming through the window may eliminate the condensation problem. A comment from one of the manufacturers was that a consumer will complain about the air infiltration problem long before condensation becomes a problem.

The cost of the current condensation resistance testing is of great concern to all of the manufacturers. If a more cost effective method of determining condensation resistance were available, such as computer simulation, the manufacturers would be more interested in using these results. Several of the manufacturers expressed concern about the form of the current Temperature Index number and find it to complicated to explain to consumers. A simpler means of comparing products for condensation resistance would be more useful.

The manufacturers were asked if they had ever seen any evidence of insulated glass (IG) failure as a result of condensation. Some of the manufacturers have seen situations where moisture from condensation has made its way into the chamber under the IG unit, causing the IG unit to fail. Other manufacturers have experienced IG failure problems that they suspected were a result of condensation getting in under the IG unit, but could not prove this to be true. One manufacturer explained the situation this way, "the window will be exposed to rain on the outside for short periods of time and when the rain stops wind will usually dry the window, but condensation will form on the inside of the window for extended periods of time and if the moisture gets under the IG unit it could be there for a while".

4.0 Computer Modeling of a PVC Fixed Window for Condensation Resistance

A simple PVC fixed window was modeled using the VISION (VISION 1995) and FRAME (FRAME 1995) computer programs. The window was modeled using the standard modeling techniques in both programs to determine the centre-of-glass temperature and U-value, and the total-window U-value. The window was then modeled using the two-dimensional convection analysis option in VISION and the convection analysis option in the FRAME program. The window was modeled using environmental conditions to match those used in the physical test for condensation resistance. The environmental conditions are included in Table 5.

Table 5 Environmental Conditions for Computer Modeling

	Interior	Exterior
Air Temperature (°C)	20	-30
Surface Heat Transfer Coefficient	Glass - Calculated by VISION Frame - 7.6 W/m^2C	30 W/m^2C

The window was modeled with 24 different insulating glass unit options. The glass options are described in Table 6. Options 1 through 12 describe the glass configurations with a metal spacer and are repeated in options 13 through 24 with a warm edge foam spacer. The centre-of-glass and total window U-values are reported. The centre-of-glass temperature (T_{cg}), centre-glass and edge-glass interface temperature ($T_{cg/eg}$), temperature 50 mm up from the frame sightline (T_{50mm}), sightline temperature ($T_{sightline}$), and coldest frame temperature (T_{frame}) are all reported. The Temperature Index for the glass (TI(50mm) at 50 mm up from the sightline), the frame (TI frame), and the window TI (the greater of TI(50mm) and TI frame) have been calculated. The U-value, temperature and TI values are all included in Table 6. The Temperature Index values determined by simulation are only an indication to the window TI values. Simulation can not account for corner effects or the effects of air infiltration. The relative difference in TI value determined by simulation will give a very good indication of the improvement in the TI value that could be achieved from one window to another.

Table 6 PVC Fixed Window Modeling Results

Option	Glass Option	Spacer Option	Ucg	U total	Tcg	Tcg/ eg	T 50mm	Tsight line	T frame	TI 50mm	TI frame	TI
1	Clear_Air_Clear	Metal	2.81	2.82	2.5	-2.3	-2.8	-12.4	-1.9	54.4	56.2	54.4
2	Clear_Ar_Clear	Metal	2.64	2.68	3.5	-0.9	-1.3	-11.6	-1.4	57.4	57.2	57.2
3	Clear_Air_Lowe (e=.22)	Metal	2.14	2.26	6.5	0.5	-0.1	-12.1	-1.8	59.8	56.4	56.4
4	Clear_Ar_Lowe (e=.22)	Metal	1.87	2.03	8.0	2.4	1.9	-11.1	-1.2	63.8	57.6	57.6
5	Clear_Air_Lowe (e=.04)	Metal	1.86	2.03	8.1	1.4	0.8	-12.0	-1.7	61.6	56.6	56.6
6	Clear_Ar_Lowe (e=.04)	Metal	1.55	1.77	10.0	3.8	3.2	-10.9	-1.1	66.4	57.8	57.8
7	Clear_Air_Clear_Air_Clear	Metal	1.76	1.92	8.7	4.3	3.8	-9.7	-0.2	67.6	59.6	59.6
8	Clear_Ar_Clear_Ar_Clear	Metal	1.62	1.81	9.5	5.5	5.0	-8.9	0.2	70.0	60.4	60.4
9	Clear_Air_Clear_Air_ Lowe (e=.04)	Metal	1.23	1.48	11.9	5.8	5.1	-10.1	-0.6	70.2	58.8	58.8
10	Clear_Air_Clear_Ar_ Lowe (e=.04)	Metal	1.07	1.35	12.9	7.0	6.4	-9.7	-0.4	72.8	59.2	59.2
11	Lowe (e=.04)_Air_Clear_ Air_Lowe (e=.04)	Metal	0.95	1.24	13.7	7.8	7.0	-9.1	0.0	74.0	60.0	60.0
12	Lowe (e=.04)_Ar_Clear_ Ar_Lowe (e=.04)	Metal	0.75	1.07	14.9	9.4	8.7	-8.2	0.6	77.4	61.2	61.2
13	Clear_Air_Clear	Warm Edge	2.81	2.74	2.5	-1.7	-2.1	-7.4	1.5	55.8	63.0	55.8
14	Clear_Ar_Clear	Warm Edge	2.64	2.59	3.5	-0.3	-0.6	-6.1	2.2	58.8	64.4	58.8
15	Clear_Air_Lowe (e=.22)	Warm Edge	2.14	2.16	6.5	1.1	0.6	-6.6	1.9	61.2	63.8	61.2
16	Clear_Ar_Lowe (e=.22)	Warm Edge	1.87	1.93	8.0	3.1	2.7	-4.9	2.9	65.4	65.8	65.4
17	Clear_Air_Lowe (e=.04)	Warm Edge	1.86	1.92	8.1	2.1	1.6	-6.2	2.1	63.2	64.2	63.2
18	Clear_Ar_Lowe (e=.04)	Warm Edge	1.55	1.65	10.0	4.5	4.0	-4.4	3.2	68.0	66.4	66.4
19	Clear_Air_Clear_Air_ Clear	Warm Edge	1.76	1.78	8.7	5.3	4.9	-1.9	5.0	69.8	70.0	69.8
20	Clear_Ar_Clear_Ar_ Clear	Warm Edge	1.62	1.66	9.5	6.5	6.2	-0.7	5.8	72.4	71.6	71.6
21	Clear_Air_Clear_Air_ Lowe (e=.04)	Warm Edge	1.23	1.32	11.9	6.7	6.2	-2.3	4.7	72.4	69.4	69.4
22	Clear_Air_Clear_Ar_ Lowe (e=.04)	Warm Edge	1.07	1.19	12.9	8.0	7.6	-1.2	5.3	75.2	70.6	70.6
23	Lowe (e=.04)_Air_Clear_ Air_Lowe (e=.04)	Warm Edge	0.95	1.08	13.7	8.9	8.3	-0.6	5.7	76.6	71.4	71.4
24	Lowe (e=.04)_Ar_Clear_ Ar_Lowe (e=.04)	Warm Edge	0.75	0.91	14.9	10.6	10.1	0.9	6.7	80.2	73.4	73.4

The simulation data was sorted based on the glass TI values and included in Table 7. The results in Table 7 indicate the improvement in glass TI value for each of the upgrades in the window. These results show that an improvement of 26 points on the TI scale could be achieved for the glass in this window. The simulation results have also been sorted based on the frame TI values and included in Table 8. The rankings of the upgrades is different for the frame than the glass. The most notable difference in the ranking is that the warm edge spacer makes more difference in the frame TI values than any of the glass changes including triple glazed with two low-e coatings and argon gas fill. These results show that an improvement of 17 points on the TI scale could be achieved for the frame in this window. The results have also been sorted based on the window TI values and included in Table 9. The results in Table 9 reveal that the window TI value can be defined by either the glass or the frame depending on the design.

Three of the windows simulated had similar construction to three of the windows found in the literature review phase of this project. Window W-13 from the literature review and window option 1 from the computer modeling had similar construction. Window W-13 had a TI value of 58 and window option 1 had a value of 54. Window W-19 and W-20 from the literature review and window options 16 and 18 all have very similar constructions. Window W-19 and W-20 both have a TI of 64, window option 16 has a TI of 65, and window option 18 has a TI of 66. This limited set of data does show that on fixed windows, where air infiltration is not a concern, computer simulation is predicting reasonable Temperature Index values.

Table 7 PVC Fixed Window Modeling Temperature Index (TI) Results Sorted by TI (50mm)

Option	Glass Option	Spacer Option	TI (50mm)	TI frame	TI
1	Clear_Air_Clear	Metal	54.4	56.2	54.4
13	Clear_Air_Clear	Warm Edge	55.8	63	55.8
2	Clear_Argon_Clear	Metal	57.4	57.2	57.2
14	Clear_Argon_Clear	Warm Edge	58.8	64.4	58.8
3	Clear_Air_Low-e (e=.22)	Metal	59.8	56.4	56.4
15	Clear_Air_Low-e (e=.22)	Warm Edge	61.2	63.8	61.2
5	Clear_Air_Low-e (e=.04)	Metal	61.6	56.6	56.6
17	Clear_Air_Low-e (e=.04)	Warm Edge	63.2	64.2	63.2
4	Clear_Argon_Low-e (e=.22)	Metal	63.8	57.6	57.6
16	Clear_Argon_Low-e (e=.22)	Warm Edge	65.4	65.8	65.4
6	Clear_Argon_Low-e (e=.04)	Metal	66.4	57.8	57.8
7	Clear_Air_Clear_Air_Clear	Metal	67.6	59.6	59.6
18	Clear_Argon_Low-e (e=.04)	Warm Edge	68	66.4	66.4
19	Clear_Air_Clear_Air_Clear	Warm Edge	69.8	70	69.8
8	Clear_Argon_Clear_Argon_Clear	Metal	70	60.4	60.4
9	Clear_Air_Clear_Air_Low-e (e=.04)	Metal	70.2	58.8	58.8
20	Clear_Argon_Clear_Argon_Clear	Warm Edge	72.4	71.6	71.6
21	Clear_Air_Clear_Air_Low-e (e=.04)	Warm Edge	72.4	69.4	69.4
10	Clear_Air_Clear_Argon_Low-e (e=.04)	Metal	72.8	59.2	59.2
11	Low-e (e=.04)_Air_Clear_Air_ Low-e (e=.04)	Metal	74	60	60.0
22	Clear_Air_Clear_Argon_Low-e (e=.04)	Warm Edge	75.2	70.6	70.6
23	Low-e (e=.04)_Air_Clear_Air_ Low-e (e=.04)	Warm Edge	76.6	71.4	71.4
12	Low-e (e=.04)_Argon_Clear Argon_ Low-e (e=.04)	Metal	77.4	61.2	61.2
24	Low-e (e=.04)_Argon_Clear Argon_ Low-e (e=.04)	Warm Edge	80.2	73.4	73.4

Table 8 PVC Fixed Window Modeling Temperature Index (TI) Results Sorted by TI frame

Option	Glass Option	Spacer Option	TI (50mm)	TI frame	TI
1	Clear_Air_Clear	Metal	54.4	56.2	54.4
3	Clear_Air_Low-e (e=.22)	Metal	59.8	56.4	56.4
5	Clear_Air_Low-e (e=.04)	Metal	61.6	56.6	56.6
2	Clear_Argon_Clear	Metal	57.4	57.2	57.2
4	Clear_Argon_Low-e (e=.22)	Metal	63.8	57.6	57.6
6	Clear_Argon_Low-e (e=.04)	Metal	66.4	57.8	57.8
9	Clear_Air_Clear_Air_Low-e (e=.04)	Metal	70.2	58.8	58.8
10	Clear_Air_Clear_Argon_Low-e (e=.04)	Metal	72.8	59.2	59.2
7	Clear_Air_Clear_Air_Clear	Metal	67.6	59.6	59.6
11	Low-e (e=.04)_Air_Clear_Air_ Low-e (e=.04)	Metal	74	60	60.0
8	Clear_Argon_Clear_Argon_Clear	Metal	70	60.4	60.4
12	Low-e (e=.04)_Argon_Clear_Argon_ Low-e (e=.04)	Metal	77.4	61.2	61.2
13	Clear_Air_Clear	Warm Edge	55.8	63	55.8
15	Clear_Air_Low-e (e=.22)	Warm Edge	61.2	63.8	61.2
17	Clear_Air_Low-e (e=.04)	Warm Edge	63.2	64.2	63.2
14	Clear_Argon_Clear	Warm Edge	58.8	64.4	58.8
16	Clear_Argon_Low-e (e=.22)	Warm Edge	65.4	65.8	65.4
18	Clear_Argon_Low-e (e=.04)	Warm Edge	68	66.4	66.4
21	Clear_Air_Clear_Air_Low-e (e=.04)	Warm Edge	72.4	69.4	69.4
19	Clear_Air_Clear_Air_Clear	Warm Edge	69.8	70	69.8
22	Clear_Air_Clear_Argon_Low-e (e=.04)	Warm Edge	75.2	70.6	70.6
23	Low-e (e=.04)_Air_Clear_Air_ Low-e (e=.04)	Warm Edge	76.6	71.4	71.4
20	Clear_Argon_Clear_Argon_Clear	Warm Edge	72.4	71.6	71.6
24	Low-e (e=.04)_Argon_Clear_Argon_ Low-e (e=.04)	Warm Edge	80.2	73.4	73.4

Table 9 PVC Fixed Window Modeling Temperature Index (TI) Results
Sorted by window TI

Option	Glass Option	Spacer Option	TI (50mm)	TI frame	TI
1	Clear_Air_Clear	Metal	54.4	56.2	54.4
13	Clear_Air_Clear	Warm Edge	55.8	63	55.8
3	Clear_Air_Low-e (e=.22)	Metal	59.8	56.4	56.4
5	Clear_Air_Low-e (e=.04)	Metal	61.6	56.6	56.6
2	Clear_Argon_Clear	Metal	57.4	57.2	57.2
4	Clear_Argon_Low-e (e=.22)	Metal	63.8	57.6	57.6
6	Clear_Argon_Low-e (e=.04)	Metal	66.4	57.8	57.8
9	Clear_Air_Clear_Air_Low-e (e=.04)	Metal	70.2	58.8	58.8
14	Clear_Argon_Clear	Warm Edge	58.8	64.4	58.8
10	Clear_Air_Clear_Argon_Low-e (e=.04)	Metal	72.8	59.2	59.2
7	Clear_Air_Clear_Air_Clear	Metal	67.6	59.6	59.6
11	Low-e (e=.04)_Air_Clear_Air_ Low-e (e=.04)	Metal	74	60	60.0
8	Clear_Argon_Clear_Argon_Clear	Metal	70	60.4	60.4
12	Low-e (e=.04)_Argon_Clear_Argon_ ow-e (e=.04)	Metal	77.4	61.2	61.2
15	Clear_Air_Low-e (e=.22)	Warm Edge	61.2	63.8	61.2
17	Clear_Air_Low-e (e=.04)	Warm Edge	63.2	64.2	63.2
16	Clear_Argon_Low-e (e=.22)	Warm Edge	65.4	65.8	65.4
18	Clear_Argon_Low-e (e=.04)	Warm Edge	68	66.4	66.4
21	Clear_Air_Clear_Air_Low-e (e=.04)	Warm Edge	72.4	69.4	69.4
19	Clear_Air_Clear_Air_Clear	Warm Edge	69.8	70	69.8
22	Clear_Air_Clear_Argon_Low-e (e=.04)	Warm Edge	75.2	70.6	70.6
23	Low-e (e=.04)_Air_Clear_Air_ Low-e (e=.04)	Warm Edge	76.6	71.4	71.4
20	Clear_Argon_Clear_Argon_Clear	Warm Edge	72.4	71.6	71.6
24	Low-e (e=.04)_Argon_Clear_Argon_ Low-e (e=.04)	Warm Edge	80.2	73.4	73.4

5.0 Conclusions

The review of the condensation resistance literature suggests that there can be very large variations in Temperature Index values for windows of very similar construction. The result of the NRC round robin testing indicate that the difference in TI values could be a result of the differences in testing from one laboratory to another. The Air-Ins pressure cycling study suggests that the differences could also be attributed to differences in the quality of construction of the windows.

The survey of window manufacturers reveals that the major concern about condensation is cost of dealing with call backs. The window manufacturers surveyed have all made design changes to their products to reduce condensation problems and the primary reason was to reduce call backs. The manufacturers all reported very small numbers of call backs and attribute this to the use of warm edge spacers. The problems they do see are a result of very high humidity levels. The manufacturers stated that in their opinion air leakage and condensation are separate problems. Air infiltration problems can lead to condensation, but the air infiltration is not a condensation problem. Some of the manufacturers have experienced insulated glass failures as a result of condensation problems.

Only three of the window manufacturers have tested for Temperature Index. The high cost of testing for condensation resistance is a problem for manufacturers. The manufacturers did express interest in computer simulation as a more cost effective method of determining condensation resistance. The window manufacturers do not see much value in testing for condensation resistance. In the new construction market builders are not interested in condensation resistance. In the renovation market the current Temperature Index is to complicated to explain to consumers.

The results from the computer simulation phase of this study give an indication of the level of improvement in Temperature Index values that can be achieved for many of the currently available upgrades in insulating glass units. While the Temperature Index values determined by simulation are only an indication to the window TI values these results indicate that computer simulation may be able to predict condensation resistance.

6.0 Recommendations

Based on the available condensation resistance data, a review of the current test procedure and standard should be conducted. The variation in Temperature Index values from one laboratory to another needs to be addressed.

The comments of the window manufacturers on the difficulty they see in explaining the Temperature Index to consumers either requires more work to explain the TI values to manufacturers so they can use the rating or a new method of comparing window for condensation resistance. The method of comparing windows for condensation resistance must be in a form that the consumer can understand.

The comments from window manufacturers and the results of the computer simulation study suggest that computer simulation as a tool to predict condensation resistance needs to be investigated further. The current computer tools need more work to improve their ability to predict surface temperatures and to output the appropriate data to determine a condensation resistance rating.

7.0 References

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Appendix A

Questionnaire for Manufacturer Survey on Condensation Resistance

Questionnaire for Manufacturer Survey on Condensation Resistance

1. Have you considered window condensation as an issue in your business?

2. Have you ever tested for condensation resistance? If yes, why did you test?

3. How did you use these results?

4. Have you ever modified your products to reduce condensation? If so what type of change did you make?

5. What kind of feedback do you get from consumers regarding condensation?

6. Do you see the certification program including condensation resistance as important?

7. Does air leakage affect condensation?

8. Would the you find simulation of condensation resistance useful?

9. What do you tell consumers to do about condensation?

10. Do you have any evidence of condensation leading to premature IG failure?