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Publisher's version / Version de l'éditeur:

Sustainable Energy Choices for the 90's: 16th Annual Conference of the Solar Energy Society of Canada [Proceedings], pp. 165-173, 1990

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NRCC-35997

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A version of this document is published in / Une version de ce document se trouve dans:
Building Envelope Performance and Durability, IRC Technical Seminar, Held in 11 Cities across Canada, February through March 1995, pp. 165-173

A UNIVERSAL APPROACH TO LABORATORY ASSESSMENT OF THE CONDENSATION POTENTIAL OF WINDOWS

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ABSTRACT

Condensation on window assemblies is one of the main issues of concern to window designers, specifiers, architects, engineers, and home owners. In addition to obstructing vision through the glazing, condensation contributes to damaging the window frame and exterior walls.

Many factors influence condensation on the glazing, sash or frame of the assembly. In addition to the indoor and outdoor environmental conditions, other factors include: window design, materials used in making the window, the position of the window in the rough opening, and the existence of blinds and convection heaters or warm air diffusers near the window frame.

Because condensation on the window surfaces is an important aspect of the overall performance of the assembly, the A-440-M84 window standard included a test procedure to rate the thermally broken metal windows for condensation. Using a "reference" glazing system, the test procedure was designed to determine the difference between an average glazing temperature and the temperature of the coldest spot on the sash or frame (at a 50 ^{o}C temperature difference across the window).

During the last decade, the window industry has gone through many changes as a result of advancements in the physical and engineering sciences. The availability of improved glazing systems made it necessary to develop a new test procedure to assess the condensation potential of windows because the existing method could not reflect the improved performance of the glazing systems.

With support from Canada Mortgage and Housing Corporation (CMHC), a new test procedure and a methodology to assess the condensation potential of windows were developed at the Institute for Research in Construction (IRC), National Research Council of Canada (NRCC). They include the determination of a temperature index of the glazing and frame/sash members of the assembly. Using these temperature indices and the desired outdoor winter design conditions of a given location, the maximum relative humidity that the assembly could withstand without condensation can be determined.

The new procedure was then introduced to the Canadian Standards Association (CSA) to replace the previous method in the CSA A-440 window standard. The revised version of the standard (due early in 1990) will include this procedure and methodology as an optional test for all window types, and will provide details and examples to demonstrate the benefits of the new procedure.

This paper provides a summary of the new procedure to assess the condensation potential of windows. It also gives a summary of the results of the round robin test performed by IRC and three private testing laboratories in Canada. The application of the new procedure in three different climatic regions in Canada is illustrated through some examples.

1. INTRODUCTION

Windows usually have the lowest thermal resistance among the various elements that make the building envelope. During winter conditions, it is possible that the indoor surface temperature of the glazing, sash or frame becomes relatively low. When the temperature of the indoor window surface is lower than the dew point temperature of the surrounding environment, condensation occurs on that surface.

Condensation on window surfaces is of concern to window designers, specifiers, architects, engineers, and home owners. Prolonged condensation on window surfaces may indicate the existence of one or more source of deficiency that may lead to system failure. For example, excessive air leakage through the window assembly, low thermal resistance of the window, or ineffective thermal break of a metal window are some of the reasons contributing to condensation on windows. In addition to obstructing vision through the glazing, continued condensation may result in rotting of wood members and cause structural damage to the building envelope.

Condensation may occur on the glazing, sash and/or frame elements of the window. The factors affecting the occurrence and pattern of condensation include indoor and outdoor environmental conditions, system design and installation, the position of the window in the rough opening, the presence of blinds and heating ducts relative to the assembly, and materials used in making the window.

Condensation potential (or resistance), is therefore, considered among the main characteristic performance of windows. Professionals as well as home owners are interested in using a window that does not have any condensation problems after being installed in a specific project. Therefore, window performance standards usually include a method to assess the condensation potential of the assembly, in addition to the other performance ratings such as structural, air leakage, and water leakage.

This paper provides a summary review of the standard methods to assess the condensation potential of windows. It also gives the details of a universal approach developed at the Institute for Research in Construction (IRC), National Research Council of Canada (NRCC), to assess the condensation potential of window assemblies. Also included are the results of a round robin test performed by four different Canadian testing laboratories using the new test method to determine the condensation potential of a number of windows.

In addition, the paper provides examples of the application of the new procedure in the assessment and selection of windows (with regard to condensation potential) in three climatic regions in Canada.

2. BACKGROUND

A number of test methods exist to assess the condensation potential of window assemblies. These methods vary in the manner in which windows are rated or assessed, and as a result confusion may occur when comparing the rating of the same window when evaluated according to these different methods.

For example, the test method developed by the Architectural Aluminum Manufacturers Association (AAMA) [1] determines the Condensation Resistance Factor, CRF, for a window when tested at a specified set of indoor/outdoor conditions. The CRF is a ratio between two temperature differences: (an average surface temperature - cold side temperature) and (warm side - cold side temperatures).

This CRF is based on an area weighted average temperature of glazing, sash and frame surface temperatures. The method uses an "arbitrary" weighting factor and "an arbitrary temperature adjustment (of 10 ^{o}F) " to calculate the average surface temperature from the measured glazing, sash and frame temperatures. These arbitrary factors are not explained in the standard, and are used for all types of metal windows. In addition, the surface temperatures are measured by means of a large number of thermocouples (at least 14 elements) placed on the various members of the window assembly. This usually results in disturbing the boundary layer on the surface of the specimen, and consequently may result in a misrepresentation of the actual surface temperatures.

Finally, the standard states that the CRF may not predict the first location where condensation occurs, but it provides a comparative performance rating for similar products. This may be acceptable for comparing products, but is not adequate to determine whether or not condensation will occur on a specific window in a given environmental condition.

Sasaki [2] introduced the concept of Temperature Index method to assess the condensation resistance of windows (the definition of the Temperature Index is given in the next section). However, the method was not generalized to assess the condensation potential of windows as related to winter design temperatures and geographic locations. The data presented in Reference 2 was limited to the units tested, and the author indicated that the final answer regarding the suitability of the test method may be obtained by comparing test results of a number of testing labs.

The 1984 edition of the Canadian window standard, CSA A-440-M84 [3] included a test method for rating of metal windows with thermal breaks for condensation resistance. The test method was intended to compare different frames to a "standard" glazing system.

The main principle of the procedure set in the A-440 standard is to minimize the temperature differential between the glass and frame or sash members. With the recent development in advanced glazing systems, this method may result in misrepresentation of the condensation resistance rating of windows. For example, if the thermal performance of the glazing is improved, the relative performance of the sash or frame drops and a lower rating would result [4]. On the other hand, if the thermal performance of the glazing portion of a window is downgraded without changes in the sash or frame characteristics, the window could achieve higher rating. These anomalies in the test method and performance requirements resulted in a review of the condensation resistance rating in the CSA A-440 standard.

Due to changes in window designs (including improvements in glazing, sash and frame members), it became necessary to develop a new procedure to assess the condensation potential for windows. With support from Canadian Mortgage and Housing Corporation (CMHC), the Institute for Research in Construction, National Research Council of Canada developed a procedure to assess the condensation potential for windows. In addition, the new procedure provides a methodology which helps in selecting windows for specific installations in various climatic regions.

The test method and procedure presented in this paper was adopted by the CSA committee on window performance, and is included, as an optional test, in the 1990 issue of the window standard (CAN/CSA A-440-M90) [5].

3. METHODOLOGY

The objective of the new method is to assess the condensation potential for windows taking into account glazing, sash or frame design. The method should address the thermal characteristic of each element of the window assembly and be able to detect the potential for condensation on the window components without a comparison with other "reference" units.

One way of achieving this objective is to relate the condensation potential of a window to its thermal transmission properties, and using the surface temperature to determine the condensation potential of the assembly. The parameter which relates the thermal characteristics of a window to its surface temperature is the Temperature Index, I.

For a specified room-side and weather-side film coefficients, the index, I, is a unique parameter of the assembly and is defined as follows:

$$I = \frac{T_s - T_c}{T_h - T_c} \times 100\% \qquad (1)$$

where:

T_s = surface temperature, ^oC
T_c = weather-side temperature, ^oC
T_h = room-side temperature, ^oC

It should be noted that different temperature indices may be determined for glazing, sash and frame members of the window assembly. Using the parameter I and the room-side and weather-side air temperature, then the maximum relative humidity the assembly, or any of its components, can sustain without condensation could be determined. This will be illustrated with examples later in this paper.

Because the Temperature Index is a function of the window design and the material used in making the window, it is not affected by the values of the room-side or weather-side temperatures. Test results have shown that when the room-side temperature was 20 °C and the weather-side changed from -7 to -35 °C ((T_h-T_c) varied from 27 to 55 °C), the Temperature Index varied only by two percent. Therefore, for convenience and consistency among the commercial testing laboratories, the room-side and weather-side air temperatures are specified in the standard at 20 and -30 °C respectively.

The maximum relative humidity a window can sustain without condensation may be determined using the Temperature Index I, the indoor temperature T_i, the winter design temperature for a given location T_d, and the psychrometric chart.

The indoor surface temperature, T_s, at a given winter design temperature, T_d, is determined as follows, using Equation (1):

$$T_s = T_d + 0.01 \times I x(T_i - T_d) \qquad (2)$$

The surface temperature, T_s, is equal to the dew point temperature where condensation would occur. Thus using the psychrometric chart (a schematic is shown in Figure 1), the intersection of the vertical line at indoor

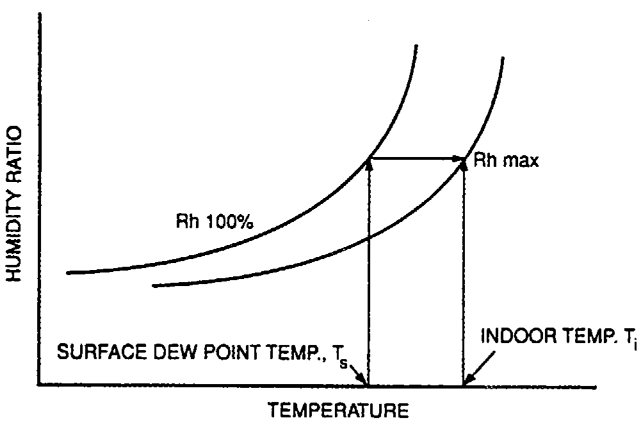

Fig.1 Schematic Diagram Showing the Relationship Between the Dew Point Temperature and the Maximum Relative Humidity on the Window Surface.

temperature, T_i, and the horizontal line at the dew point temperature (which is equal to the surface temperature T_s), gives the maximum relative humidity, R_h %, the surface can sustain without condensation at the specified conditions.

For simplicity, a chart (see Figure 2) was constructed to show the relationship between

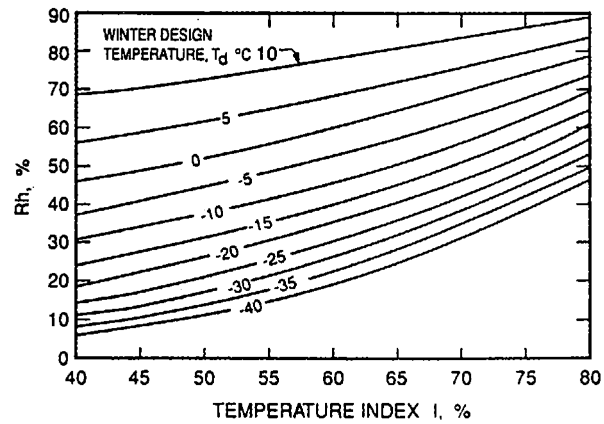

Fig. 2 Relationship Between I and Max R_h for Winter Design Temperature T_d, at Indoor Temperature T_i = 20°C.

the Temperature Index, I %, and the maximum relative humidity, R_h %, for various winter design temperatures, T_d, for most of the locations in Canada. This chart is based on an indoor air temperature, T_i, of 20 °C. Similar charts could be constructed for other indoor temperatures.

4. TEST PROCEDURE

In this section, a brief description of the test procedure to determine the Temperature Index is highlighted. More details about the test facility and window mounting are given in References 5 and 6.

The test consists of mounting the window in a surround panel separating room-side (warm-side) and weather-side (cold-side) of the environmental chamber. The room-side and weather-side temperatures are maintained at 20 ±1 °C and -30 ±1 °C respectively. The heat transfer is by natural convection on the room-side, whereas wind is blown perpendicular to the window surface on the weather-side at a speed creating a film coefficient of 22±3 $W/(m^2.K)$.

Thermocouples are placed on the glazing, sash and frame members of the window as shown in Figure 3. The positions of the thermocouples

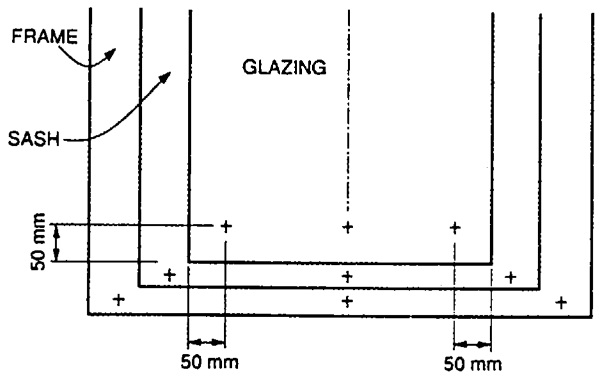

Fig. 3 Thermocouple Locations on Glazing, Sash and Frame.

are intended to measure the lowest temperature on the window elements. It is, however, possible that the glazing temperature gets lower in locations closer to the edge of glass, especially when metal spacers are used.

The test is performed with no air leakage through the specimen by maintaining 0$\pm$ 5 Pa pressure differential across the window assembly.

5. RESULTS OF THE ROUND ROBIN TEST

With the cooperation from the CMHC, a round robin test was performed on a selected set of windows. In addition to IRC/NRCC, three other Canadian testing laboratories were involved in the round robin test. Four different windows were tested by each laboratory, and IRC tested seven windows. Table 1 gives a brief summary description of the windows tested, and more details about the windows are given in Appendix A.

Although efforts were made by all laboratories to use the same temperature conditions, the final results were reported at different T_c and T_h. For the purpose of comparing the surface temperature reported by the laboratories participating in the round robin test, normalized frame and glazing temperatures were calculated (T_{nf} and T_{ng} respectively).

These normalized surface temperatures are based on a temperature differential of 50° between room-side and weather-side air (i.e. T_c = -30 °C, and T_h = 20 °C), and are determined as follows:

$$T_{nf} \text{ or } T_{ng} = \frac{T - T_c}{T_h - T_c} \times 50 - 30^{\circ}C \qquad (3)$$

Where T_c and T_h are the weather-side and room-side temperatures, respectively, used during testing at each laboratory.

The tabulated Temperature Index, I, was calculated based on the lowest value of T_{nf} and T_{ng} (T_n), as follows:

$$I = \frac{T_n + 30}{50} \times 100\% \qquad (4)$$

Table 2 gives a summary of the normalized glazing and frame temperatures (T_{ng} and T_{nf} respectively), and Table 3 gives a summary of the calculated Temperature Index based on the lowest of T_{ng} and T_{nf}.

6. EXAMPLES OF APPLICATION

As indicated earlier, the Temperature Index method is used to determine the maximum relative humidity a window can sustain without condensation at a given environmental conditions (e.g. winter design conditions). For a given window, the use of this method requires the determination of the unit's Temperature Index, I. This is usually done in a testing laboratory, using the test procedure described in this paper.

Using the chart shown in Figure 2, the intersection of I and the winter design temperature of the location where the window will be installed, gives the required maximum relative humidity, R_h.

To illustrate the use of the new method, consider a window with a Temperature Index I = 50 %. Also, assume that the window will be installed in Vancouver, Toronto and Saskatoon. Using I = 50%, and Figure 2, the maximum relative humidity (R_h%) in Vancouver, Toronto and Saskatoon are: 41, 28 and 14, respectively.

Another way of using this method is to determine the Temperature Index of a window suitable for installation in specific locations (e.g. Vancouver, Toronto and Saskatoon). This is particularly useful for professionals during the selection process of windows for a specific project.

Assume that the indoor environmental conditions are as follows: indoor temperature is 20°C, and indoor relative humidity is 35%. Using the psychrometric chart, this yields a dew point temperature T = 4 °C.

At T = 4°C, T_h = 20°C and T_c = winter design temperature for Vancouver, Toronto and Saskatoon (-7, -18 and -35°C, respectively), then the Temperature Index is equal to (using Equation (1)): 41%, 58% and 71%, for Vancouver, Toronto and Saskatoon, respectively.

7. DISCUSSION

The use of the Temperature Index method to assess the condensation potential of windows proved to be simple, flexible, and provides a means to select windows for specific applications. Because the Index is a unique parameter related to the thermal characteristic of the unit, it does not impose restrictions on its application with respect to window types or materials. Experimental data showed that aluminum, vinyl or wood windows could be assessed for condensation potential using the above described method.

The round robin test results indicate that when the laboratories closely follow the procedure, as outlined in the A-440 standard, comparable and repeatable results could be obtained. There were, however, some differences when comparing the test results obtained from the participating laboratories in the round robin test. These differences were as high as 7% of the calculated Temperature Index, which is within the acceptable limits of uncertainty in most commercial laboratories. Some of the possible reasons for these differences include:

- the accuracy of measurements,
- locations of the thermocouples,
- the method of attaching thermocouples to the window surface,
- the extent of boundary layer disturbance by thermocouple leads,
- variability of the sample tested (four windows of the same type and manufacturer were distributed to the four labs to save time),
- the precision of determining the film coefficient on both sides of the sample.

8. CONCLUSION

The new method to assess the condensation potential of window assembles represents a substantial improvement relative to the procedure in the CAN3-A440-M84 window standard. The applicability of the new method to all types of windows permits using it as a standard method. Among the advantages of the new method is the ability to select windows for installation in specific projects under predetermined environmental conditions. This is of particular importance to architects, engineers and home owners.

9. REFERENCES

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10. APPENDIX A

10.1 Description of the Windows Tested

1 - **Vertical Slider:** A 1.00 m wide (W) x 1.60 high (H) x 0.102 m deep (D) aluminum frame with thermal break and two aluminum sliding sashes. Each sash contains a factory sealed double glazed unit of 3 mm clear glass with 16 mm air space.

2 - **Casement:** A 0.70 m (W) x 1.60 m (H) x 0.102 m (D), aluminum frame with thermal break and one aluminum operable casement sash. The sash contains a factory sealed double glazed unit of 3 mm clear glass with a 12 mm air space.

3 - **Horizontal Slider:** A 1.60 m (W) x 1.00 m (H) x 0.102 m (D), aluminum frame with thermal break and four aluminum single glazed sashes: one fixed sash and three horizontal sliding sashes. The sashes are arranged as two sliding primary sashes, one fixed sash and one sliding storm sash. The two sets of sashes are 64 mm apart.

4 - **Fixed Window:** A 2.00 m (W) x 2.00 m (H) x 0.152 m (D) aluminum frame with thermal break and a central mullion separating two factory sealed double glazed fixed units of 4 mm clear glass and 14 mm air space.

5 - **Horizontal Slider:** A 1.60 m (W) x 1.00 m (H) x 0.137 m x (D), exterior vinyl clad wood frame with two vinyl clad metal horizontal sliding sashes running in vinyl tracks. Each sash contains a factory sealed double glazed unit of 3 mm clear glass with 16 mm air space.

6 - **Casement:** A 0.70 m (W) x 1.60 m (H) x 0.146 m (D), exterior metal clad wood frame with one exterior metal clad wood operable casement sash. The sash contains a factory sealed double glazed unit of 3 mm clear glass and 12 mm air space.

7 - **Casement:** Same as unit #6 with the sash replaced by another containing a factory sealed triple glazed unit with low emissivity coating on one surface.

Note: Windows #1 through #7 (inclusive) were tested by IRC. Windows #1 through #4 (inclusive) were tested by Air-Ins and Warnock Hersey labs, and windows #1, 2 and 3 were tested by ORTECH International.

TABLE 1. SUMMARY OF THE WINDOWS TESTED

Unit #	Type	Description	Tested by Lab #*
1	Vertical slider	Alum. frame with thermal break, sealed double glazed	1,2,3,4
2	Casement	same as above	1,2,3,4
3	Horizontal slider	same as above	1,2,3,4
4	Fixed	same as above	1,2,4
5	Horizontal slider	Wood with vinyl clad, sealed double glazed	4
6	Casement	Wood with metal clad, sealed double glazed	4
7	Casement	Wood with metal clad, sealed triple glazed with low emissivity coating on surface 5	4

* Laboratory #
1 Air-Ins Inc.
2 Warnock Hersey, Toronto
3 ORTECH International
4 IRC/NRCC

TABLE 2. SUMMARY OF THE NORMALIZED GLAZING AND FRAME TEMPERATURES - ROUND ROBIN TEST RESULTS

Window #	Lab #1 T_{ng} °C	Lab #1 T_{nf} °C	Lab #2 T_{ng} °C	Lab #2 T_{nf} °C	Lab #3 T_{ng} °C	Lab #3 T_{nf} °C	Lab #4 T_{ng} °C	Lab #4 T_{nf} °C
1	0.1	-0.3	-2.7	-0.3	-2.7	-5.6	-3.1	-0.4
2	0.5	-1.5	-2.9	5.8	-2.1	-0.6	-3.7	-0.1
3	0.5	-1.5	0.0	-3.4	-2.2	-4.6	-1.9	-4.6
4	-0.5	-0.5	-0.4	0.3	---	---	-4.2	-1.8
5							-2.4	-7.4
6							-3.3	-2.4
7							4.1	0.7

TABLE 3. SUMMARY OF THE TEMPERATURE INDEX I - ROUND ROBIN TEST RESULTS

Window #	Temperature Index I % Lab #1	Lab #2	Lab #3	Lab #4
1	54	54	49	52
2	57	54	56	53
3	57	53	51	51
4	59	52	--	52
5				45
6				53
7				59