Window-Wall Interface Details to Evaluate the Risk of Condensation on Box Windows

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ABSTRACT: The development of alternative details to manage water intrusion at the window-wall interface has produced a number of novel approaches to detailing the interface between the window and adjacent wall assembly. Many of these approaches advocate the need to provide drainage at the rough opening of the window subsill given that the window components themselves are susceptible to water entry over their expected life. Depending on the types of windows used and the cladding into which the windows are installed, there arise different methods to provide drainage that may also affect air leakage through the assembly. This in turn may give rise to the formation of condensation along the window at the sill or along the window sash and glazing panels. Hence there is a need to determine if, under cold weather conditions, specific interface details that incorporate sill pans provide potential for condensation on the window components in which air leakage paths may be prominent at the sill or elsewhere on the window assembly. The paper reports on a laboratory evaluation of conditions suitable for the formation of condensation at the window frame perimeter of the interface assembly as a function of both temperature differential and pressure difference across the test assembly. A summary of the laboratory test protocol is provided that includes a description of the test set-up and apparatus, fabrication details of the specimen and information on instrumentation and calibration and experimental results for one type of window (box window).

1 INTRODUCTION

Window components are susceptible to water entry over their expected life [Lacasse et al. 2007] hence there is a need to ensure the window installation details permit adequate drainage at the rough opening of the window subsill. However, providing proper drainage may also affect air leakage through the assembly and under cold weather conditions condensation may form along the window at the sill or along the window sash and glazing panels. Do window installation details that incorporate sill pans increase the risk for condensation on the window components in which air leakage paths may be prominent at the sill or elsewhere in the window assembly?

There exist several standard laboratory test methods for determining the potential for the formation of condensation on windows, however the essential aspects of such methods were first proposed by Sasaki [Sasaki, 1971] and the standardisation work carried out in AAMA [AAMA, 1972; AAMA, 1998], ASTM [ASTM, 2000] and CSA [CSA, 2004] follows on these initial efforts. These standards prescribe the overall test protocol, temperatures of the room side and cold side, and maximum relative humidity under test conditions. A useful overview of these methods is given by Elmahdy [1990].

The essential elements of the method, briefly described, consist of testing a window in a hotbox chamber, measuring the lowest window glazing and frame surface temperatures from specified locations on the window, and calculating the average exterior air temperature and the average interior air and wall surface temperatures. The “Temperature Index” (I) of the window can then be determined based on the following relationship provided in the CSA A440.2 Standard [CSA, 2004]:

$$I = (T_s – T_o) / (T_i – To) \times 100 \qquad (1)$$

where T_i and T_o are the indoor and outdoor air temperatures, and T_s is the average room-side surface temperature measured in the test. The temperature index is non-dimensional, and represents the interior surface temperature relative to the interior and exterior air temperatures.

This paper reports on a laboratory evaluation for assessing the potential for the formation of condensation at the window frame, sash or glazing for window installations that incorporate sill pans. The laboratory test method given in the CSA A440.2 standard [CSA, 2004] was used as a basis for determining the potential for the formation of condensation on windows as a function of both temperature and pressure difference across the test assembly.

2 EXPERIMENTAL SETUP AND PROCEDURE

The purpose of the test was to obtain surface temperature measurements on specific window component that thereafter permitted determining whether there existed conditions suitable for the formation of condensation given specified interior and exterior conditions. The CSA A440.2 [CSA, 2004] test method for determining condensation potential on windows, as described by Elmahdy [1990], was followed with the following exceptions: the pressure difference across the specimen was adjusted to 20 and 40 Pa and at levels in excess of that required in the standard (i.e. 0 ± 5 Pa); steady state conditions were maintained for at least 6 hours (compared to 5 h in the standard); once steady state was achieved, readings were averaged over a period of at least 2 hours; deficiencies were introduced at the wall-window interface. A guarded hotbox [Bowen 1985] was used to subject a suitable specimen, incorporating a window and related interface details, to temperature differentials specified in the test. A description of the hotbox is provided by Brown et al. [1961]. Details on the experimental procedure, the calibration of the hotbox, specimen instrumentation and data acquisition are provided in subsequent sections.

2.1 *Test setup*

In respect to the choice of installation details, consideration was only given to those details that had in a previous study [Lacasse et al., 2007] demonstrated an ability to adequately manage rainwater entry. Such installation details typically include a sloped sill with sill pan flashing incorporating a back dam. Research and analysis has been completed on installation details for flanged mounted and box windows. This paper reports on results derived from testing the installation details for box windows; results on flanged windows are given in Maref et al. [2010].

The nominal size of the test frame incorporating the wall-window interface was 1.22-m wide by 2.44-m high, and framed with 51 by 152-mm Spruce-Pine-Fir lumber. The test assembly was intended to be representative of typical North American wood frame construction practice. The exterior cladding of the assembly was hardboard wood composite siding, installed in accordance with current building practice, and directly to the sheathing membrane (Weather Resistive Barrier-WRB-spun bonded polyolefin). The membrane overlays an oriented strand board (OSB; 11-mm) wood sheathing panel affixed over the wood frame. Glass fibre batt type insulation was placed in the stud cavities adjacent to the window opening and the interior finish was gypsum board (12.7-mm). A fixed (non-operable) non-flanged PVC window (610-mm by 1220-mm) was centered vertically within the specimen. The window was installed with the glazing aligned with the plane of thermal resistance of the wall. Figure 1 provides installation details of a box window incorporating pan flashing, sloped sill, upstand and related details that help promote drainage of water from the windowsill if subjected to inadvertent water entry. Figure 1 shows the location of the plane of thermal resistance of the wall in relation to that of a box window installed along the same plane.

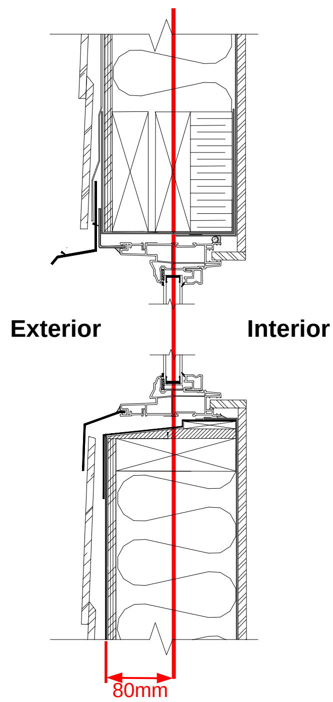

Figure 1. Installation detail for box window

The space between the window frame and wood frame wall was left empty (Test set 1), was filled with glass fibre insulation (Test set 2) or spray-in-place polyurethane foam (SPF) (Test set 3). Finally, given the interest in using installation details that included a sill pan, thought was given to possible paths of air leakage through the assembly at the sill and the type of deficiencies that might arise at these locations due to improper installation of components or premature failure of seal components. The introduction of two deficiencies at the wall-window interface provided a means to evaluate whether air leakage across different components of the window assembly caused condensation to form on the warm side of the wall assembly when leakage was induced in the test assembly. A first deficiency was located at the exterior of the wall-window interface and at the juncture of the cladding and window frame at the lower extreme corner of the window, whereas the second one was situated at the interior of the assembly at the interface between the window frame and the interior finish but located at the upper most and opposite corner of the window assembly.

2.2 *Test procedure*

Both the temperature and relative humidity (RH) were continuously monitored over the course of a test sequence in the warm side chamber and only temperature in the cold side chamber. Measurements of temperature in the chamber were made to an accuracy of ± 1.5 °C and that of relative humidity to ± 1 % RH. The data were recorded on an acquisition system and then subsequently used to ensure that steady state conditions had been maintained over the course of a test sequence. Surface temperature conditions on either side of the window and on specified window components (e.g. glazing; frame at sill and at jambs) were continuously monitored with a set of 40 thermocouples: 20 on the exterior and 20 on the interior of the specimen. The location of each of these thermocouples followed CSA A440.2-04 specifications. Thermocouples were also placed within the cavity between the window frame and window opening. Thermocouple temperature measurements were made to an accuracy of ± 0.5 °C.

Values of local "Temperature Index" (I) at given points on the window frame and glazing were determined based on relationship (2) given in EN ISO 10211 Standard (2):

$$I = (T_s – T_o) / (T_i – To) \qquad (2)$$

Tests were carried out under a pressure differential, continuously monitored during the test sequence by a pressure transducer with a 250 Pa range and accuracy of ± 1 Pa. A pressure transducer was used to monitor the pressure in the interstitial space between the window frame and window opening. The amount of airflow due to pressurization during the test was not monitored. The guarded hotbox test facility was calibrated according to the approach described in Elmahdy [1992] and Elmahdy & Bowen [1988]. The film heat transfer coefficient on the room-side and weather-side surfaces was determined from the calibration of the hot box with use of the Calibration Transfer Standard (CTS); the CTS is described in Goss et al. [1991]. For calibration, the CTS was mounted flush with the room-side surface of the surround panel.

The temperature differential for the tests was set at 50°C ± 1.5°C and the temperature sensor measurements were recorded once steady state conditions were achieved following a period of 15 minutes in these conditions (20°C – (–30°C) = 50°C). The humidity on the warm side chamber was maintained at ca. 10 % RH to ensure that no condensation occurred on any of the interior exposed surfaces of the widow frame. Tests were conducted with pressure differences of 0Pa, 20Pa and 40Pa by evacuating the warm side chamber.

3 RESULTS

3.1 *Test set 1 – no insulation*

Without a pressure difference across the specimen there was a very uniform temperature distribution over the wall, window frame and glass on the outside (cold side) of the specimen (-28.3°C to -28.7°C). This is consistent throughout all measurements, regardless of pressures and deficiencies. On the inside (warm side) of the specimen the temperature of the wall showed more variation, as could be expected. On the outside the air space between the WRB and the hardboard siding blocked any thermal bridging that might have been provided by the wood studs from appearing on the measurements. The temperature on the window frame and the insulated glazing unit (IGU) had a strong thermal gradient; whereas the temperatures on the middle and upper half of the window range from 12.4°C to 14.2°C, temperatures between 3.9°C and 8.6°C were evident near the sill. The gas inside the IGU will, when heated up, rise towards the top of the unit, resulting in a typical thermal gradient.

As the cavity between the box window and the wood framing is approximately 12 mm wide and 125 mm deep, internal convection within the cavity might induce thermal stratification in the vertical air space. This cavity is essentially open to the cavity between the hardboard siding and the wood stud wall at the sill, and closed at the jambs and the top. At the sill, the gap between the sill and the subsill is about 1.9cm. At the jambs and the top there is a slit of 0mm to 5mm wide. Gustavson (2001) studied flow patterns in different types of window frames both experimentally and with computational fluid dynamics. He concluded that cavities with interconnections of less than about 7mm can be treated as separate cavities. This of course is only valid for natural convective effects and where the influence of forced convection by external pressure gradients has not been taken into account. Based on these data one could assume that in all circumstances there would be a considerable air flow at the bottom, whereas air exchange between the wall-window interface cavity and the cavity behind the hardboard siding is rather unlikely without forced convection.

The horizontal cavity beneath the sill was located at the plane of thermal resistance of the window where the highest thermal gradient from inside to outside is evident, thus intensifying the resulting convection. Any cold air entering into this cavity will gather heat from the inner side of the window frame, and thereafter rise due to its decreasing mass density. However, due to this phenomenon one might expect a similar thermal gradient at the outside of the window

- this was not observed. A possible explanation can be found by analyzing the configuration of the window frame. This specific window profile lets the outside chamber of the frame partially act as a geometrical cooling fin, short-circuiting the location of the thermocouple. Furthermore, due to the high heat flux caused by the presence of the insulated glazing unit spacer, the effect of other components on the temperature at the thermocouple is outclassed.

The six thermocouples located in the vertical cavity confirm a strong temperature gradient over its' height (Figure 2), rising from 0.4°C at the sill to 12.9°C at the top of the cavity. The vertical thermal gradient in the cavity was monitored throughout all measurements and was consistent in nature. However, when compared to the experiments with spray foam insulation in the cavity (please refer to section 3.3), the addition of which eliminates both natural thermal stratification and forced air flow, it seems that a small part of the observed temperature gradient is caused by other effects. The mounting brackets are not close enough to the thermocouples to affect the measurement and given that this is a fixed window with no hinges or stays, neither of these items can affect results.

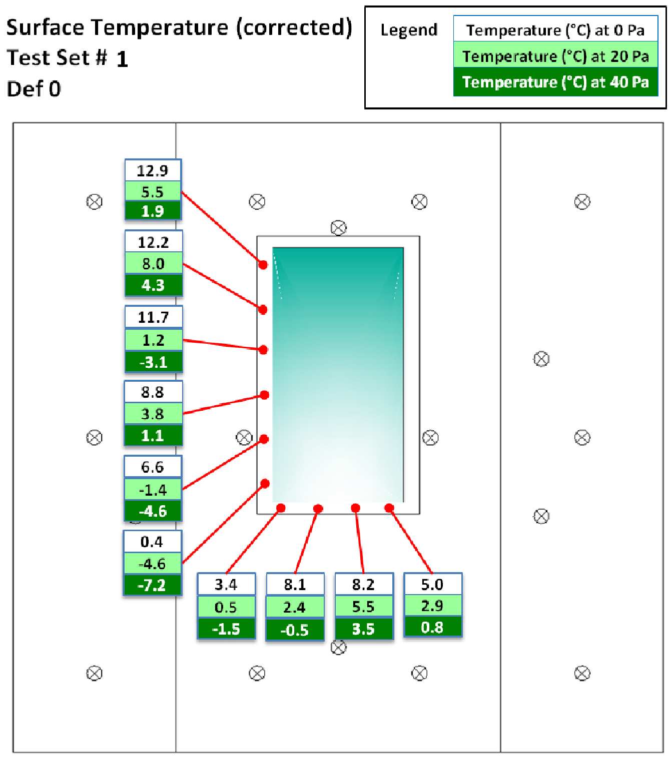

Figure 2. Surface temperatures - no deficiencies

3.1.1 *Effect of pressure differences*

In order to analyze the effect of cold air infiltrating into the assembly, a positive pressure of 20 and 40Pa was applied. Due to this unbalance, cold air was drawn into the assembly through small cracks and holes in the different components of the specimen. As there were no wilful deficiencies in this set-up, air could only enter through local imperfections of the wall, window-wall interface or window frame. Figure 3 shows a clear temperature drop on the window frame while the indoor temperature remained the same, and this is most distinct at the upper left and lower left corner of the window. In general, the temperature index dropped between 0.02 and 0.12 (on average 0.04). A temperature drop at that location can be caused by two effects:(i) air running along the perimeter of the window frame can cool the window frame, even causing the glazing stop to cool a few degrees (the thermocouples on the window frame are mounted on the glazing stop); (ii) there might be air leakage through the window frame itself. Leakage through the frame came either from outside directly through the frame to the inside or via the cavity between the window frame and the wood stud wall and thereafter though the window frame to the inside. A detailed analysis with smoke pencils indicated that the interior perimeter of the window frame was tightly sealed with caulking, so air leakage only around the window could not account for these results. By comparing these results with other test sets it was concluded that the window frame itself was quite leaky. In test set 3, SPF was installed in the cavity between the window frame and the wood stud wall. Any cooling effects would then be caused by cold air directly entering through the window from the outside to the inside. A comparison of temperature index drops on the frames showed that direct air leakage through the window frame from outside to inside accounts for about 40% of the overall temperature drop. That means the remaining 60% in temperature drop would be caused by air coming from the space between the frame and the wall into the frame.

A closer examination of several samples of the window typology used in this study revealed imperfections at the mitre joint of the welded vinyl frame. The mitre joint was chamfered after welding, but in some instances it apparently was cut off, thereby revealing a small opening (slit) at the exterior corners of the window frame. As well it was observed that at the top and bottom side of the window there were minor perforations caused by staples; these staples were used to secure the wood protection strapping in place during transport of windows. It was also evident that there were no weep holes at the bottom side of the window (contrary to good practice). In general the windows were poorly fabricated and several deficiencies were present in the frame specifically at the corners both inside and outside. These deficiencies rendered it possible for cold air to enter the frame from the outside between the window frame and the wood stud wall, and permit air to leave the frame at the interior at joints located at the glazing stops.

The effect of air leakage was most pronounced at the corners, where air could easily penetrate at the glazing stop butt joints. The temperature on the window frame decreased by as much as 4.1°C (5.9°C) at the top side and 3.2°C (3.6°C) at the bottom side of the window frame when 20Pa (40Pa) pressure was applied. Although the pressure difference is doubled, one should take into account the effect of the power law (3):

(3)

With Q: air flow rate [L/s], C: flow coefficient [L/s·Pa^n], n: flow coefficient [-]. It can reasonably be assumed that the flow exponent of the specific deficiency lies between 0.55 and 0.65 for building applications. Within this range of values for flow coefficient the air flow rate would rise between 46% and 57% upon doubling the pressure difference. Hence, one would not expect that the temperature drop would be linearly related to the pressure difference.

With regards to the condensation potential, the results differ significantly to the tests without pressure difference due to the air flows in the window frame: a temperature index of 0.68 at 0Pa, 0.64 at 20Pa and 0.63 at 40Pa. Note that without pressure difference the edge of the glass pane is the coldest spot and hence the most likely condensation surface, whereas this shifts towards the frame during pressure differences. This may seem a trivial remark, but might have major consequences. Even though condensation should be avoided at all times, it is likely to occur due to specific circumstances, e.g. extremely low outdoor temperatures or high indoor moisture loads. Condensation on the glass itself can be seen very easily by building tenants, who might react by turning up the heat, ventilate more or regularly wipe it dry. If condensation first occurs on the frame, it might not be noticed and the water might get absorbed by adjacent porous finishing components such as wood or gypsum. This could cause staining and deterioration of the materials. The temperatures at the window frame in the cavity between the window and sill are extremely low when a pressure difference is present. The thermocouple at the lower left corner shows 0.4°C at 0Pa, -4.6°C at 20Pa and -7.2°C at 40Pa. This could cause severe problems during a rapid change of air flow direction: a temperature of -7.2°C corresponds to the dew point of 20°C room air at 16% humidity, so indoor air could easily condense on that surface.

3.1.2 *Effect of deficiencies*

During the second series of tests two deficiencies were installed: one at the lower right corner on the outside and one on the upper left corner on the inside (when looking from the inside of the window). When no pressure difference is applied, results are nearly identical to the previous test without deficiency.

3.1.3 *Effect of deficiencies and pressure differences*

When a pressure difference of 20Pa is applied while deficiencies are present (see Figure 3), the outside surface temperatures remain the same, but the surface temperature of the window profile on the inside is reduced an extra 0.9°C compared to the test without deficiencies (1.3°C for 40Pa). A temperature drop of 1°C corresponds to a drop of 0.02 points in the temperature index (for the given boundary conditions of the test setup). Compared to the test with the open deficiencies but no pressure difference, the upper part of the window cools down by as much as 3.9°C at 20Pa and the lower part 4.1°C. At 40Pa that is 7.2°C and 4.9°C for the upper and lower part of the window respectively. By comparing these results with tests without deficiencies and other test setups, the overall temperature drop of the window frame (averaged results for the whole frame are used to compare general trends) can be likely attributed to three different effects. First of all, about 25% can be traced back to air leakage from outside to inside through the window frame itself (based on the results of the same window when SPF was installed). Secondly, air leakage from the cavity frame-wall accounts for ~37.5% of the temperature drop (by comparison with the setup without deficiencies). Thirdly, another ~37.5% is introduced by the air leakage between the outer deficiency and the inner deficiency. It can be concluded that about 60% of the temperature drop may have been avoided by installing high grade window frames. In terms of temperature index, the 25% corresponds to a drop of 0.02, and the 37.5% to 0.03. The combined effect is on average a change in temperature index of 0.08 (or 4°C) on the window frame, but as shown in Figure 3 peaks of up to 0.15 occurred depending on the specific location of the air leaks. The most critical reductions in temperature index from 0.69 (on the window pane) to 0.63 at 20 Pa (on the frame) and 0.61 at 40Pa (on the frame). The temperatures in the cavity show a general decrease of 5.9°C at 20 Pa and 10.1°C at 40Pa.

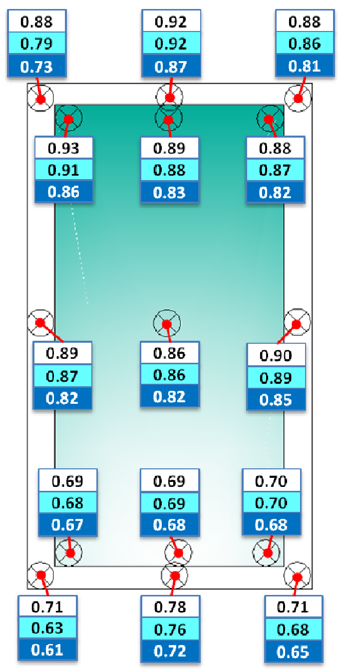

Figure 3. Temperature index at interior side when deficiencies are introduced (no insulation)

3.2 *Test set 2 –glass fibre insulation*

For this test setup the cavity between the window frame and the rough opening was filled with glass fibre insulation and caulked on the interior side. The surface temperatures on the outer side did not differ from those obtained in the test set-up without insulation (Test set 1). On the inside, the effect of adding insulation was most pronounced for the surface temperature of the window frame, which was about 0.5°C higher due to the insulation. However, this was not the case for the IGU where the temperature remained roughly the same. The lowest temperature index drops from 0.69 to 0.68 but this was not a general trend and most likely was caused by rounding. In fact the surface temperature of the glass perimeter was primarily determined by the centre-of-panel R-value of the IGU, the IGU-spacer along the edges, and the removable glazing stop of the window frame. Unless the temperature around the frame is below a certain threshold and the frame has a limited lateral thermal resistance, the effect on the IGU will be negligible. The cavity between window and wood frame itself, now packed with insulation, was on average 4.1°C warmer as compared to the setup without insulation, with peak differences of 7.6°C. It should be noted that there was still a minor thermal gradient present, albeit less pronounced than found earlier. This supports the theory concerning the effect of convection inside the vertical mullions of the window frame. A detailed analysis of the results points out that the calculated thermal gradient was smaller than that observed without insulation, but slightly bigger than the one observed with SPF insulation. This may have been caused by thermal stratification (despite the resistance of the glass fibre insulation), or by an upward air flow caused by a leak. In the latter case, it would also account for a part of the thermal gradient in the setup without insulation. In the horizontal cavity at the sill the temperature was significantly higher than the test without insulation, consistent with the predicted dampening of convection effects by the insulation.

3.2.1 *Effect of pressure differences*

Both for 20 and 40Pa pressure difference there was no important effect on the outdoor surface temperatures for the wall, for the window frame, and for the IGU. On the indoor side, the effect of pressure differences on window frame temperature was nearly identical to test setup 1. Although the absolute temperatures and temperature indexes were slightly higher due to the insulation, the shift caused by the air flow was the same. In the cavity between the window frame and the wood frame, the temperature drop was considerably lower: on average 3.6°C at 20Pa (instead of 5.9°C) and 7.8°C at 40Pa (instead of 10.1°C). The resistance of the glass fibre insulation to air flow can account for this change in temperature drop.

3.2.2 *Effect of deficiencies*

The results of the test with the two deficiencies in the construction are nearly identical to the test without deficiencies. On average the surface temperature of the window frame decreased 0.1°C, and the temperature in the cavity decreased 0.2°C. Although this might be attributed to greater convection in the cavity due to lower air flow resistance, the difference was very small and lies within the magnitude of measurement error.

3.2.3 *Effect of deficiencies and pressure differences*

While there is no effect on the outside surface temperatures due to pressure difference, a pressure difference has a small effect on the window frame temperatures on the inside. Figure 4 shows the temperature indexes for the case where deficiencies are present and a pressure difference of 40Pa is applied. The results show, from top to bottom, the test without insulation between window frame and wall, with mineral fibre insulation and SPF respectively. Without insulation, there was an additional temperature drop of 1.5°C on the interior side of the window frame compared to the same test without deficiencies. With the glass fibre insulation the additional effect of the deficiencies was negligible. While the presence and type of insulation had no effect on the temperature drop due to a pressure difference without deficiencies, it had a clear effect when the deficiencies are in fact present. This supports the theory that the overall temperature drop described above was caused by air leakage in the window frame itself, and not by air leakage in the cavity.

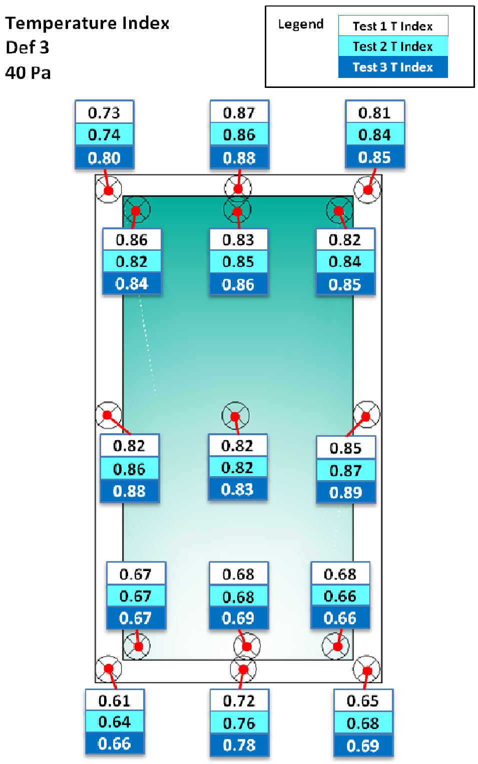

Figure 4. Temperature indexes at 40Pa with deficiencies for the different test sets.

Figure 4 shows the temperature indexes on the inside of the window, which shows that glass fibre insulation has a positive effect. The low value at the top left corner of the window frame might be attributable to minor deficiencies in the caulking, measurement accuracy or rounding. The effect on the temperature index at the interior surface is a little over 0.01, consistent with the 0.5°C increase due to the insulation (recorded in the case without pressure differences and without deficiencies). The lowest temperature index achieved at a pressure difference of 40Pa was 0.64, only slightly higher than the situation without insulation. Due to the thermal stratification of the gas in the IGU, the lowest temperature indexes can be found at the sill; hence, it is evident that the insulation will not have a major effect on results at this location.

3.3 *Test set 3 – SPF (Spray-in-place polyurethane foam)*

The application of SPF inside the cavity should prevent any convection from occurring. The surface temperatures of both the window frame as the IGU are similar to the case with glass fibre insulation and thus the same thermal criteria should apply. However, the lower right corner of the glass pane was almost 1°C colder than the setup without insulation. At the sill, SPF was installed, so similar results would be expected for the two cases with insulation (see Fig. 4). Contrary to expectations, the most critical surface temperature on the glass drops on one single point when insulation is installed in the cavity. However, the temperatures measured inside the cavity at the sill rose due to the installation of SPF because thermal stratification is prevented. Analysis of IR-pictures did not offer any explanation of the divergent results at the sill although the divergence of this anomalous value lies within the degree of uncertainty of the measurement.

3.3.1 *Effect of deficiencies and pressure differences*

Although there may be no convection in the wall-window interface cavity, a pressure difference of 20Pa results in a reduction in the surface temperature of the window frame, by 0.8°C on average, and 1.0°C for 40Pa (without insulation this was 1.6°C and 3.5°C respectively). Again, in absence of thermal effects in the cavity around the window, the cause of the reduction in temperature lies within the window frame itself. Only deficiencies in the window can permit an airflow that affects the surface temperature at that location. The temperature drop is very similar to the case with glass fibre insulation. The lowest temperature index for the SPF test is 0.66 for pressure differences of 0Pa, 20Pa and 40Pa. Deficiencies caused no change in the temperature profile with or without pressure difference. The SPF blocked any possible air flow around the cavity; hence pressure differences have no influence on the surface temperatures.

4 CONCLUSIONS

A test protocol has been developed to determine the condensation potential of windows based on existing CSA A440.2 test standard but that also includes a means to determine the effects of air leakage on the risk for condensation on windows. The windows were installed in a wood frame assembly typical of cold climate North American construction practice. The installation details were those that promote the management of rainwater entry and incorporate such features as a sloped sill, sill pan flashing membrane, and back dam. Air leakage across the wall-window interface may increase the likelihood that condensation forms on the window frame. Hence, deficiencies simulating either the improper installation of components or the premature failure of critical seals have been included in the evaluation to verify the degree to which such openings influence the risk of condensation. The risk of condensation is first determined in conditions where no deficiencies are present at the wall-window interface and thereafter, a series of defects are included that permit air, in varying degrees, to penetrate the interface. In each instance, the surface temperatures of the window were monitored to establish any changes in comparison with the instance where no defects were present. This series of experiments were first conducted with no insulation in the cavity between the window unit and the openings and thereafter with mineral fibre insulation and polyurethane spray-in-place foam. This permitted comparison of these approaches to window installation in terms of the impact of insulation on mitigating the risk of condensation.

The following observations and analysis were made on experimental results for window-wall interfaces installed with box windows:

The exterior side of the configuration is not sensitive to thermal effects induced by air leakage to the inside. As a result the use of IR-scans may not be useful for air leakage detection from the outside.

The temperatures on the insulated glazing unit show a significant vertical thermal gradient, and the spacer around the perimeter acts as an additional thermal bridge causing low surface temperatures in all configurations. However, the IGU is not very sensitive to the changes occurring inside the cavity between the window frame and the rough opening: the effect was limited to about 1°C and was likely caused by imperfections in the window frame.

The box window used in the measurements was of lesser quality, as several cracks and deficiencies in the window frame, in certain instances, directly affected results. Even for the installation with SPF without deficiencies it was observed that the surface temperature on the window profile dropped 1°C, possibly caused by insufficient airtightness of the window frame.

Installing insulation in the cavity has a strong effect on the temperature inside the cavity; however, the rise in interior surface temperature on the window frame is limited to 0.5°C.

Air flow around the window caused a temperature drop up to 2.5°C at 20Pa without deficiencies and 4.0°C at 40Pa with deficiencies on the interior window profile. This corresponds to a change in temperature index of 0.04 and 0.09 respectively. By installing glass fibre insulation, the temperature drop was 2.5°C and 2.7°C respectively, and for SPF 1.0°C and 1.5°C. Thus by installing glass fibre insulation the temperature remained the same without deficiencies, but it prevented air flow around the window when deficiencies are present. SPF has a more pronounced effect on the results: both with (2.5°C) as without deficiencies (1°C) the frame is significantly warmer.

As the window installation was tested under severe circumstances (50°C and 40Pa difference between interior and exterior climate), the overall effect of air flows is rather limited, and the bulk of it is likely caused by deficiencies in the window frame itself. However, these results are only valid for the vinyl frame used in this study.

Convective air transport around the window was partly retarded by the installation of glass fibre insulation. Only the use of spray foam insulation provided a seal to the perimeter thereby avoiding cooling of the window profile.

Future research will focus on the validation of dynamic simulation tools and convective heat transfer coefficients to assess the condensation risk for different interfaces. Based on the results obtained from experimental data and dynamic simulations comprehensive design guidelines will be published to assess the condensation risk based on outdoor temperature, indoor temperature and internal moisture loads. Ultimately it is expected that the information developed from these tests will provide guidance to window manufacturers, window installers and knowledgeable practitioners on the thermal performance of differing window installation methods.

5 ACKNOWLEDGEMENTS

The authors wish to thank the Canada Mortgage and Housing Corporation for partial funding of the project and acknowledge the contributions of Mr. Silvio Plescia, Senior Researcher, Canada Mortgage and Housing Corporation to this paper.

REFERENCES

AAMA 1972. *Voluntary Test Method for Condensation Resistance of Windows, Doors and Glazed Window Sections*. Publication No. AAMA 1502.3-1972, Architectural Aluminium Manufacturers Association.

AAMA 1998. *Voluntary Test Method for Thermal Transmittance and Condensation Resistance of Windows, Doors and Glazed Wall Sections*. Publication No. AAMA 1503-98, Architectural Aluminium Manufacturers Association

ASTM 2000. *ASTM C1199-00 Standard Test Method for Measuring the Steady-State Thermal Transmittance of Fenestration Systems Using Hot Box Methods*. ASTM Book of Standards, Vol. 04.06, ASTM Publications, PA, USA.

Bowen R.P. 1985. *DBR's Approach for Determining the Heat Transmission Characteristics of Windows*, Building Research Note, 234, 12 p.

Brown W.P., Solvason K. R., and Wilson A.G. 1961. A unique hot-box cold-room facility. *ASHRAE Transactions*, Vol. 67, pp. 561-577.

CSA 2004. Energy performance of windows and other fenestration systems/User guide to CSA A440.2-04. Canadian Standards Association, Mississauga, Canada, 142 p.

Elmahdy, A.H. 1992. Heat transmission and R-value of fenestration systems using IRC hot box : procedure and uncertainty analysis, *ASHRAE Transactions*, 98 (2): pp. 630-637;

Elmahdy, A.H., Bowen, R.P. 1988. Laboratory determination of the thermal resistance of glazing units, *ASHRAE Transactions* 94 (2): pp. 1301-1316

Elmahdy, A.H. 1990. A Universal approach to laboratory assessment of the condensation potential of windows, Sustainable Energy Choices for the 90's : 16th Annual Conference of the Solar Energy Society of Canada, Halifax, N.S., Canada, pp. 165-173.

EN ISO 10211, 2007. Thermal bridges in building construction – heat flows and surface temperatures – Detailed calculations. CEN, Brussels, Belgium.

Goss, W.P.; Elmahdy, A.H.; Bowen, R.P., 1991, Calibration transfer standards for fenestration systems**,** In-situ Heat Flux Measurements in Buildings : Applications and Interpretation of Results : Proceedings, S.N. Flanders Ed.; U.S. Army Cold Regions Research and Engineering Laboratory. Special report, SR 91-03, p.251-260.

Gustavson A., Griffith B.T., Arasteh D., 2001. Three-Dimensional Conjugate Computational Fluid Dynamics Simulations of Internal Window Frame Cavities Validated Using Infrared Thermography, *ASHRAE Transactions* 2001, Vol. 107, Pt 2.

Khalifa, A-J. N., 2001. Natural convective heat transfer coefficient – a review. 1. Isolated vertical and horizontal surfaces. Energy conversion and management 42: 491-504.

Lacasse M.A., Manning M.M., Rousseau M.Z., Cornick S.M., Plescia S., Nicholls M., Nunes S.C. 2007. *Results on assessing the effectiveness of wall-window interface details to manage rainwater*. 11th Canadian Building Science and Technology Conference, Banff, Canada. pp. 1-14.

Maref W., Van Den Bossche N., Armstrong M., Lacasse M.A., Elmahdy H. and Glazer R. 2010. *Laboratory Tests of Window-Wall Interface Details to Evaluate the Risk of Condensation on Windows*, submitted to: ASTM Symposium on Condensation in Exterior Building Wall Systems, October 2010, San Antonio, US.

Sasaki, J.R. 1971. Developing a standard test for window condensation performance. *Materials Research and Standards*, 11 (10), pp. 17-20.