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Construction Technology Update No. 5

Window Condensation in Historic Buildings that Have Been Adapted for New Uses

by W.C. Brown

When a heritage building is adapted for a new use, changes to the indoor environment can lead to condensation problems. This Update describes an evaluation of selected windows undertaken by IRC researchers at Ottawa's Laurier House (now being used as a museum) to determine their effectiveness in controlling condensation.

The evaluation of a heritage or 'historic' building to determine how it will perform under new conditions involves the following steps: identifying the specific uses to which the building will be put; establishing the temperature and relative humidity needed to support this use; determining the climatic conditions in which the building has to operate (i.e., the winter design temperature, which is readily available for any location in Canada) and determining the actual performance of the building envelope through a program of monitoring. Such a program may demonstrate that the level of performance the building provides is adequate for the proposed use under the proposed conditions and that no modifications are required.

Figure 1. Laurier House

The objectives of the IRC project were:

1) to examine the building, review the current situation and determine which building envelope elements required further investigation; and
2) to recommend operating/refurbishing strategies, if necessary, to improve the moisture performance of the various building envelope elements.

A New Use for Laurier House

Laurier House, a designated National Historic Site, was built in 1878. The former residence of Canadian Prime Ministers Sir Wilfrid Laurier and Mackenzie King is now being used as a museum.

For the former inhabitants of Laurier House, indoor conditions in winter probably included a temperature of 18°C and a relative humidity (RH) of between 20% and 30%. However, the extensive collection of historical artifacts now housed there requires constant indoor conditions in winter of 21°C and 35% RH.

The use of Laurier House as a museum requires that the building envelope be able to control condensation under the proposed operating conditions. This control is a function of the design and construction of the elements that comprise the building envelope, and of the indoor and outdoor environments. (The winter design temperature for Ottawa is -25°C.)

construction

Published by

Institute for Research in Construction

IRC

The high humidity levels required by the new use combined with Ottawa's low winter design temperature suggested that a large quantity of condensation might form on the windows and in the walls. While maintenance records available for Laurier House did not provide adequate information about past condensation performance, water staining on the sills of many of the windows indicated that condensation had occurred.

Because of this evidence of previous condensation problems, combined with the fact that windows are particularly susceptible to condensation (because they usually have the lowest thermal resistance among the various elements that make up the building envelope), the evaluation of the windows at Laurier House was conducted first.

It should be noted that the presence of condensation on the windows does not necessarily mean that condensation is occurring in the walls. It is also the case that strategies for dealing with condensation on windows can differ from those required to address condensation in walls.

In order to determine whether effective condensation control was being achieved by the windows as-found, and to predict their condensation performance under the proposed operating conditions, selected windows, in their original ('historic') condition, were instrumented with thermocouples and monitored by IRC researchers.

Temperature Monitoring of 'Historic' Windows

Laurier House has two types of windows:

- wood-frame, single-hung windows
- metal-frame, leaded-glass casement windows.

All windows are single-glazed and all storm windows are wood-frame. For the single-hung windows, the storm windows are mounted on the exterior, as usual; for the casement windows, they are mounted on the interior (because the casement windows open outward).

To evaluate condensation resistance, the researchers selected two windows of each type (see Figure 2). For each type, one of the windows was less airtight than the other,

Principles of Condensation Control

For condensation to occur, a surface has to be at or below the dew point temperature of the adjacent air. This is the temperature at which the vapour in an air-vapour mixture begins to condense. Condensation forms on the glazing, sash, or frame elements of a window more readily than elsewhere in the building envelope because the window is typically colder.

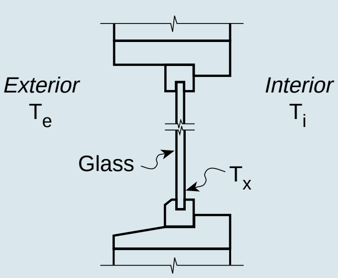
One measure of the condensation potential of the indoor environment is its dew point temperature, which is related to its moisture content. For air at a temperature of 21°C and an RH of 35%, for example, the dew point temperature is about 5°C.

The temperature index (I_x), which relates the interior surface temperature of a window or wall to the exterior temperature and the thermal characteristics of the window or wall, is a measure of condensation resistance. The index is defined as

$$I_x = \frac{(T_x - T_e)}{(T_i - T_e)}$$

where
T_x is the surface temperature;
T_e is the weather-side (exterior) air temperature; and
T_i is the room-side (interior) air temperature.

(Note: The temperature index can also be expressed as a percentage.)



What the formula for temperature index actually states is that the more the room-side surface temperature of the window can be like the indoor temperature, the greater the condensation resistance. This relationship therefore links the condensation resistance of glazing to its thermal performance and thereby to its design.

Increased condensation resistance is achieved by improving the thermal performance of the window.

The temperature index will normally be constant over the range of conditions to which buildings are subjected and it can be treated as a property of the assembly. A high temperature index is required for applications with a high indoor relative humidity, or a cold outdoor design temperature, or both, in order to minimize condensation on the interior surface.

When the temperature index for a particular window or wall in combination with the winter design temperature of the location of the building element is known, the interior relative humidity sustainable by that building element without condensation occurring can easily be determined. Using the same approach, the temperature index (I_x) that a window requires to sustain a particular RH can be determined. For example, where an RH of 30% and an indoor temperature of 21°C is required, windows with a temperature index of 0.60 are needed to prevent condensation.

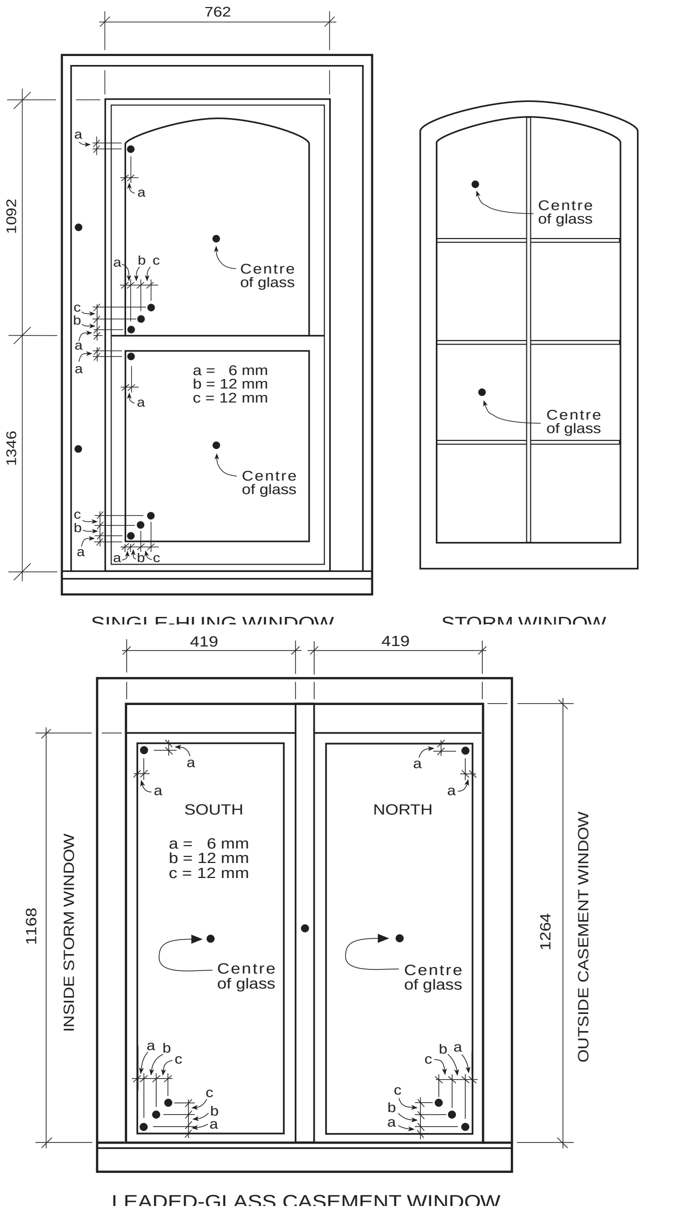


Figure 2. Windows showing locations of the thermocouples. Thermocouples were located at the corners of the windows (where the temperature tends to be the coldest and therefore where condensation is most likely to occur) as well as at the centre (where condensation is least likely to occur). Not only does this arrangement allow for measuring the temperature index at a particular point, but also for determining the area of the window that would likely experience condensation. For the single-hung windows, thermocouples were located around the frame in order to assess whether the construction of the frame (i.e., the presence of counter weights contained in the frame) had an adverse effect on the condensation potential of the frame. As well, thermocouples were placed on the storm window to help assess how it contributes to the total performance of the window.

i.e., one was left unaltered, while the other was sealed at the inner surface. All windows were monitored for a minimum of one week during late February/early March using thermocouples installed at various locations on the windows to record the temperatures.

The collected data were used to calculate the temperature index (I_x) at these various locations, and the condensation resistance (condensation potential) of a particular window was then deduced from the temperature indices. The condensation potential of a window can be evaluated in conditions other than those that actually produce condensation — that is, the evaluation does not have to be carried out under condensation conditions.

The temperature and relative humidity of the interior air, exterior air, and the air from a diffuser located in the floor were also measured as was the relative humidity in the space between the prime and storm windows of one of the single-hung windows.

While the windows were being tested, the interior temperature was maintained between 22°C and 23°C at an RH between 20% and 30%.

To obtain representative data, the room environments were kept in their normal operating state for the duration of the monitoring so that the thermal environment of the windows would not change. For example, blinds for the single-hung windows, normally halfway closed, were left in this position while the windows were monitored. No blinds were mounted in front of the metal casement windows.

Results of Evaluating the Windows

For both types of windows, the measured temperature indices showed that condensation would occur at exterior temperatures of -10°C and lower, if the interior conditions were maintained at 21°C with an RH of 35%. Given that the winter design temperature for Ottawa is -25°C, it is clear that significant condensation will occur on the windows unless measures are taken to prevent it.

Single-hung wood windows. Condensation will occur on the (exterior) storm windows, unless the (interior) single-hung windows are made airtight to prevent air leakage through holes and air-permeable materials. No condensation, however, will be found on the wood frames of the prime windows.

Metal casement windows. The temperature indices on the metal casement windows indicate that condensation will occur unless the storm windows, fitted on the room side, are made airtight.

Dealing with Excessive Condensation on ‘Historic’ Windows

Three options are available to address window condensation at Laurier House:

1. Accept that condensation will occur and be prepared to
   a) remove it (by mopping, etc.) daily, and
   b) refinish the window surfaces annually.

2. Change the interior environment adjacent to the window so that the window surface is at or above the dew point temperature thus preventing condensation from occurring on it.
3. Improve the thermal performance of the windows.

The first option requires the least intervention with regard to the 'historic' fabric of the building, but requires a permanent commitment on the part of the owner to ensure that moisture accumulation is temporary and that finishes are maintained. The second option requires significant intervention in that a source of heat or dry air, or both, is required. These measures singly or in combination would ensure that the dew point of the air adjacent to the window is less than the temperature of the window. The third option probably provides the best long-term control of condensation on the windows and warrants a closer look.

In the case of an historic building, the choice of strategy depends on the degree to which historical authenticity and/or the original aesthetic must be maintained and on the maintenance and operating budgets available. So while it appears that Option 3 is the best one, there may be factors which render it unacceptable or not viable.

Improving the Thermal Performance of 'Historic' Windows

Recommended improvements depend on the type of window, and on the conditions in which they have to function.

Single-hung wood windows. The thermal performance of the glazing of the single-hung windows can be improved by implementing one of two measures:

- replacing the single-glazed pane in the prime window with low-emissivity (low-e), sealed double-glazed units; or
- adding a third layer (the storm window provides the second layer) of glazing, either single or double, to the interior of the window.

Either measure will provide sufficient improvement in thermal performance to reduce condensation on the glazing to an acceptable level. **Note:** The exterior storm windows would be left unchanged in both cases.

In the case of Laurier House, the sash of the wood windows happens to be thick enough to accommodate a sealed, double-glazed unit with 3-mm-thick glass and a 13-mm-deep air space. Such a replacement unit with an aluminum spacer and a low-e coating has a thermal resistance of approximately RSI-0.35 in the centre of the glass and RSI-0.20 at the edge. Warm-edge technology (WET) spacers would further improve the thermal performance at the edge of the sealed unit, especially at the corners.

Adding a third layer of glazing to the interior of the window would form an additional air space, helping to increase the RSI value of the single-hung window. That, in turn, would increase the temperature of its room-side surface, thereby preventing condensation.

Metal casement windows. The thermal performance of the metal casement windows can be improved by replacing the single-glazed storm (i.e., interior) windows with low-e, sealed, double-glazed units. These units would be the same as those suggested as replacements for the single-hung windows.

These inner storm windows would need to be installed in an airtight manner so that there is no moisture from leaking air that could condense on the casement windows. (**Note:** In any window system, it is always the innermost window that must be airtight.)

Conclusions

By establishing the condensation characteristics of the windows, owners of historic buildings considering their reuse can determine whether measures have to be taken to prevent condensation from occurring on the windows or whether they are able to provide acceptable performance under the proposed use and operating conditions in their as-found condition.

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May 1997
ISSN 1206-1220

"Construction Technology Updates" is a series of technical articles containing practical information distilled from recent construction research.

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