

# Predicting Time-to-Fogging of Insulating Glass Units

G. R. Torok<sup>1</sup>

## ABSTRACT

The service life of an insulating glass unit is considered to have come to an end when water vapour condensation (fog) has developed internally on glass surfaces, obscuring clear vision. Estimates for time-to-fogging from manufacturers, consultants and others vary widely, without any clear consensus on a reasonable length of time. Standard laboratory performance assessment methods, such as CGSB-12.8 or ASTM E 774 et al. in North America, were intended to improve short-term durability to beyond the typical manufacturer 5-year warranty period and have been successful in this regard, but as a result are no longer correlated to life span and thus cannot now be used to estimate time-to-fogging. This same limitation applies to newer, similar standards such as ASTM E 2190 et al. Accurate time-to-fogging estimation is necessary for building owners who must (or choose to) establish and maintain capital repair and replacement funds that include replacement of insulating glass units. An aggressive accumulation of funds would result from a pessimistic assumption of time-to-fogging whereas an inadequate accumulation would result from an optimistic assumption; in both cases, the effect would be unnecessary short-term financial hardship. An accurate method to assess remaining service life span ('time-to-fogging') is required.

The time-to-fogging of insulating glass units installed in buildings can be estimated based on repeated measurement of the dew point temperature of the cavity gas fill, analysis of the trend of increase, and extrapolation of the trend to future years. Coincidence of the extrapolated trend with normal outdoor ambient air temperatures reveals time-to-fogging. The efficacy of this Canadian method was assessed via a laboratory program funded through the CMHC External Research Program. This method, the test program and outcomes are detailed in a report published by CMHC in early 2006. A summary of the report is presented in this paper.

Further research has revealed a precedent for the test program by the Norwegian Building Research Institute as part of a study of long-term field performance of insulating glass units in 1963. The study and its outcomes are summarized in this paper, and are presented together with a summary of another prediction method proposed as an outcome of a study to correlate the ASTM E 773 and 774 laboratory performance assessment methods to field performance in the 1980s in the USA, previously reported in the CMHC report and elsewhere. A critical assessment of both methods supports the method developed by the author. Further research is also presented regarding the influence of temperature on cavity gas fill dew point temperature suppression by desiccants which confirms that time-to-fogging predictions should be based on dew point temperature measurements made during warm weather.

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# Predicting Time-to-Fogging of Insulating Glass Units

G. R. Torok

## INTRODUCTION

Insulating glass units are a marvel of modern technology. The most common form of insulating glass unit consists of two panes of glass, separated by a spacer containing one or more desiccants, and held together by organic or inorganic sealants. Various glasses, spacers, sealants, and gases to fill the unit cavity are available to enhance thermal, acoustic, and fire performance, well beyond what could be provided just a few decades ago with single panes of glass. However, in one respect modern insulating glass units are inferior to single glazing: whereas single glazing could, conceivably, last the entire life of a building (barring physical damage), for the most part, insulating glass units cannot and will require replacement, often several times during the life of a building.

Generally, insulating glass units are replaced when a loss of vision occurs due to the condensation of water vapour on the inaccessible glass surfaces within the unit. Although the unit may still be functioning as an environmental separator, it no longer provides an unobstructed view to the exterior and thus is replaced for aesthetic reasons.

The need to plan for replacement is, perhaps, of little financial significance for older buildings with relatively small 'punch' style windows that include small quantities of insulating glass. Replacement costs are small and if spread out over time, can be dealt with as a day-to-day operating expense. However, a cursory examination of modern high-rise residential apartment buildings in most urban centres in Canada would reveal that the proportion of the building envelope comprised of glazing – windows, window-walls, curtain walls, sloped glazing, skylights and glazed doors – has been steadily increasing over the last 20 to 30 years. Replacement costs for insulating glass units have similarly grown and now form a significant part of long-term capital reserve replacement fund plans. A recent survey for CMHC revealed that for high-rise residential condominium buildings in the greater Toronto area, for large scale, building-wide replacement programs, estimated costs for insulating glass unit replacement vary from about \$50,000 to about \$2,400,000 per building, depending on the size of the building and on the proportion of the building envelope incorporating insulating glass units.<sup>1</sup> Setting aside adequate funds for replacement is difficult if time-to-fogging is uncertain: a pessimistic (shorter than necessary) time estimate can burden owners with excessive contribution rates to capital reserve plans whereas a pessimistic (longer than necessary) time estimate can give owners a false sense of security followed by short-term deficit make-up that can be even more onerous.

In addition to 'routine' replacement of insulating glass units, accurate time-to-fogging prediction may be of more value to high-visibility commercial buildings that are glazed with insulating glass units incorporating tinted and / or reflective glass. Such glasses become obsolete from time to time and when replacement is required, glass of matching appearance (and performance) may not be available. The overall appearance of the building may suffer, reducing its value compared to adjacent buildings, affecting the owner's income. This can be expected to become a bigger issue in the future as the trend toward the use of neutral appearance, relatively clear, high-performance low-e coated glass continues and demand for, and thus availability of tinted, reflective glasses decreases further<sup>2</sup>. Therefore, time-to-fogging estimation is of value for both residential and commercial occupancy buildings.

## **METHODS OF FIELD ESTIMATION OF SERVICE LIFE**

### **NORWEGIAN ‘WEST COAST FIELD STUDY 1963’**

The Norwegian Building Research Institute (NBRI) carried out a field survey of insulating glass units installed in windows in buildings on the west coast of Norway in the early winter of 1963. The survey, known as ‘The West Coast Field Study 1963’ expanded on two earlier field studies of insulating glass unit performance by NBRI in 1959 and 1960. Insulating glass units first became available in Norway in 1950. A total of 2,040 units of ten types installed from 1951 to 1963 were examined. Units were visually examined for condensation on glass surfaces sealed within the cavity, scumming of glass surfaces caused by repeated condensation, cracked glass, cracked metal spacers, and deflection (bowing inward between corners). The dew point temperature of the cavity gas (plain air) of units without visible damage (cracked glass and / or metal spacers) was also measured. In total, dew point measurements were obtained for 1,895 units.<sup>3</sup>

Most of the ten unit types studied had been available in Norway for only a few years. Four had been available six years or longer but production of one had ceased about two years before the field study. Of the remaining three, two were essentially the same, being licensed versions of ‘Thermopane’ by Libbey-Owens-Ford (LOF) in the USA (lead strip spacer soldered to copper strips fused to the perimeter, cavity-side faces of the glass panes, with the cavity flushed with dry air prior to sealing; no desiccant) manufactured in Belgium and Germany and shipped to Norway. The remaining type, ‘Polyglass’ was also manufactured in Belgium and shipped to Norway (tubular aluminum spacer containing silica gel desiccant, glued to the glass panes with a “plastic glue”, with a stainless steel band around the perimeter to clamp the glass panes and spacer together). For these three types, analysis of measured dew point temperatures revealed a warming trend with age; that is, the older the unit, the warmer the dew point temperature. Extrapolation of the curves of dew point temperature vs. year of manufacture suggested life spans of at least thirty years, although this was considered by the report author to be unlikely given that other units examined were visibly damaged (glass and / or spacer cracks); some of the intact units also had been installed as replacements to units of the same type that had failed. Also, recall that dew point measurements were made of intact units. Thus the extrapolated service life spans were likely overly optimistic.

The problems with extrapolation arise from generating a trend line from a series of single measurements of different units of progressively greater age. This assumes that manufacturing methods remain constant and that the service environment conditions – window frame type, installation details, exposure, etc. – are also identical. The study author recognized both shortcomings. Manufacturing methods were known to remain unchanged for ‘Thermopane’ type units for the ages of unit studied but changes were made for the ‘Polyglass’ type. For both ‘Thermopane’ and ‘Polyglass’ units, it was assumed that the older units were still intact partly because their service environment was more protected from the elements and other adverse conditions, so in that respect service environment conditions were similar. Thus, errors in extrapolation for the ‘Thermopane’ units should have been less than for the ‘Polyglass’ units. Unfortunately, follow-up studies do not appear to have been carried out to determine if the extrapolated service life span predictions were correct.

### **AMERICAN ‘FIELD CORRELATION STUDY’, 1980 – 1989**

In 1980, the Sealed Insulating Glass Manufacturers Association (SIGMA) in the USA began a ‘Field Correlation Study’ to track the performance of approximately 2,400 insulating glass units installed in 140 buildings in 14 cities in the continental USA. It was known by this time that the service life span of insulating glass units had been improved considerably with the development and instituting of performance test standards, beginning with work at the Division of Building

Research at the National Research Council of Canada in the late 1950s leading to the development of the Canadian Government (later General) Standards Board (CGSB) 12-GP-8 standard (later CGSB-12.8) standard and later, in the mid 1960s, by the American Society for Testing and Materials (ASTM) leading to the development of the E 773 and E 774 standards.<sup>4</sup> As such, the assumed correlation between the test regimes and field performance had improved beyond an assumed five years; the intent of the study was to determine what might be the (then) current correlation.<sup>5</sup>

For the first nine years of the study, insulating glass units were visually examined and the dew point temperature of the cavity gas fill was measured. The consultant to SIGMA who carried out the field measurements, Jim Spetz, developed the following relationship of dew point temperature to likelihood of fogging:

- dew-point less than -80°F (-62°C): there is almost no moisture in the insulating glass unit cavity, thus the units can be expected to have a “very long expected future clear life,”
- dew-point between -80°F (-62°C) and 0°F (-18°C): there is some moisture in the cavity, thus the unit can be expected to have a future clear life less than units with a dew-point temperature less than < -80°F (-62°C),
- dew-point between 0°F (-18°C) and +32°F (0°C): there is “considerable” moisture in the air space, thus the units will have a relatively short future life. Estimation of remaining life span requires knowledge of the construction of the units, including the desiccant type and manufacturer, so that the water vapour content of the cavity gas can be correctly estimated, and
- dew-point greater than 32°F (0°C): permanent fogging of glass surfaces within the cavity can be expected to develop within two years.

Spetz authored two (2) articles in the 1980s<sup>6,7</sup> in industry periodicals but there does not appear to have been any further, formal development of this method. As it stands, the method can be used to make a long-term estimate of time-to-fogging of insulating glass units but as noted for the third category of measured dew point temperatures (between 0°F (-18°C) and +32°F (0°C)), specific knowledge of construction of the tested units is required so that appropriate technical data on measured dew point temperature vs. water vapour content can be obtained from the desiccant manufacturer. In older buildings, such knowledge may be difficult, if not impossible, to obtain, especially if the insulating glass manufacturer is unknown or no longer in business. This is a significant limitation. Without this information, advice can only be given that fogging is now imminent; only in the fourth category of measured dew point temperatures (greater than 32°F (0°C)) can an estimate of remaining service life span be made. Unfortunately, the stated remaining service life space (permanent fogging within two years) is far too short to allow a building owner sufficient time to accumulate funds necessary for insulating glass unit replacement, particularly in large, modern high rise buildings in which insulating glass units form a substantial part of the building envelope.

## **CANADIAN PREDICTION METHOD**

### **GENERAL**

The limitations to the prediction schemes described could be overcome as follows:

- instead of measuring the cavity dew point temperatures of units of the same type but different age, the cavity dew point temperature of units of the same age would be measured at different times,

- analyze the dew point temperature data collected over a number of years to determine a warming trend and project the trend (extrapolate) until it coincides with normal outdoor ambient air temperatures; the time from last measurement until coincidence would be the time-to-fogging.

This approach would also eliminate the need to obtain specific information on the desiccant and other aspects of construction of the subject units because repeated measurements and trend analysis should reveal performance of the system as a whole, and would include the effects of desiccant(s) and unit construction. Variations in service environment, degradation of materials, etc., to date would also be taken into account. Barring substantial changes in service environment or material degradation, the prediction of time-to-fogging should be accurate and thus avoid overly optimistic (as in the NBRI study) or pessimistic predictions of time-to-fogging.

#### LIMITATIONS

It would be remiss to avoid identifying two significant limitations to this, and the previous two approaches: firstly, dew point temperatures must be measurable and secondly, sufficient sets dew point temperatures measured over time must be available to establish a trend.

Dew point temperatures are commonly measured with equipment that uses solidified carbon dioxide ('dry ice') as a cooling source. Dry ice sublimates at about  $-79^{\circ}\text{C}$  but heat gain through the test equipment and from the test unit increases the minimum temperature that can be attained to about  $-73^{\circ}\text{C}$ . As long as the dew point temperature of the cavity gas is colder, it cannot be measured and predictions of time-to-fogging cannot be made. In the Norwegian study, dew point temperatures were measurable within the first year of installation but as noted, the quality of insulating glass units has increased considerably since then such that today, dew point temperatures should not be measurable for many years after manufacture and installation. Thus, a measurement and prediction program is not likely to begin until the building has aged several years. In the meantime, a reasonable life span must be assumed. This would be based on experience, preferably at the building under study with similarly constructed insulating glass units (ie. in an existing building in which an insulating glass unit replacement program has been completed) but if not possible (ie. for newly constructed buildings) then from buildings of similar site, situation, occupancy, general construction, window system, and insulating glass unit construction. Periodic sampling should be carried out to identify the first instance of measurable dew point temperatures so that an accurate, building-specific measurement and prediction program can be initiated, as soon as possible.

At least three sets of measurements over time are needed to perform prediction calculations. This allows for non-linear predictions. This was not a limitation with the Norwegian study since units of different ages were studied although as discussed, it is more advantageous to study the same units over long periods of time. Spetz's scheme attempts to overcome this by giving fixed relationships of performance and dew point temperature, so that a prediction of time-to-fogging could be made from a single set of dew point temperature measurements although as discussed, effective application relies upon specialist knowledge and availability of desiccant performance data which may not be available for older units. Thus, a measurement and prediction program must extend over at least three, and preferably more, time periods; the periods should be equal in length. For condominium ownership buildings, it would be rational to coordinate measurement with capital repair and replacement budget updates.

## PROCEDURE

The procedure for measurement of existing cavity dew point temperatures, calculation of trend, and prediction of time-to-fogging is described following:

### 1. TEST UNIT SELECTION

Ideally, units should come from the same population – that is, the units should be of the same age, construction and made by the same manufacturer. Mixing units of different ages, construction and manufacturers that conceivably might have different times to fogging can be expected to produce a muddled result. Unit similarity is easily determined if the manufacturer participated in certification programs of the Insulating Glass Manufacturers Alliance (IGMA), the Insulating Glass Manufacturers Association of Canada (IGMAC) or CMHC, all of which required labeling of units with the manufacturer name, location of manufacture (city), year of manufacture and certification number. These certification programs required periodic re-testing of units to maintain certification and prohibited significant changes in manufacture and manufacturing facility (ie. relocation of the factory) between re-tests so it is reasonable to assume that units by the same manufacturer, made about the same time, with identical visible assembly details (spacer type and joinery, sealants) were likely constructed about the same.

Once populations of different units are identified (if present), consideration should be given to subdividing the populations to allow monitoring and prediction of potentially different times to fogging for units in with markedly different service environment conditions. For example, orientation has a marked effect on time-to-fogging because of differences in solar gain and thus, UV radiation exposure and temperature.<sup>2,8</sup> In congested urban situations differences in solar gain can also occur within elevations where the lower floors could be permanently shaded by an adjacent building but upper floors are fully exposed and sunlit. In residential apartment buildings in which insulating glass units are laid-in glazed from the interior of the building, wetting of sealants by room-side surface condensation and accumulation of run-off within frames would affect sealant condition, performance and unit service life.<sup>9,10,11</sup> Service conditions that can affect longevity of insulating glass units are discussed in more detail in the CMHC study report described later<sup>12</sup> and elsewhere.

Ideally, sample sizes for groups of units to be monitored should established following standard rules for statistical analysis and monitoring. However, in situations in which there are many groups to monitor, the size and number of samples may be dictated more by the cost of the service and available funds rather than statistical rules.

### 2. DEW POINT MEASUREMENT

Dew point measurements can be made with the test apparatus described in ASTM E 576 (Figures 3 and 4). This is the apparatus used by Spetz. Dry ice is placed into an insulated cylinder and forced to one end, against one of a pair of intermeshed aluminum blocks, by a sprung disk. The contact area between the blocks can be adjusted, thus allowing the temperature of the block not in direct contact with the dry ice to be varied; one face of this block is placed in direct contact with the room-side surface of the insulating glass unit to be tested (Figure 1). The unit is left in contact with the glass for several minutes, removed, and the glass examined for evidence of condensation or frost on the cavity-side surface. By adjusting the temperature of the aluminum block in contact with the glass, the glass can be cooled in stages until condensation occurs, revealing the dew point temperature of the cavity gas (Figure 2). The procedure for measurement of dew point temperatures with this device is described in more detail in the ASTM E 576 standard.



**Figures 1 and 2:** Field dew point measurement apparatus, as described in ASTM E 576. At left, the apparatus is mounted on an insulating glass unit in contact with the inboard pane of glass. A digital thermometer measures the temperature close to the glass surface. At right, the apparatus has been removed (except for the suction cups), revealing a circle of condensation or frost on the cavity-side surface of the pane induced by the chilled contact area of the apparatus.

The potential range of dew point temperatures can be quite large. It can be as low as the temperature to which the equipment cool the glass surface (about  $-73^{\circ}\text{C}$ ) and as high as the outdoor ambient air temperature (it cannot be higher, otherwise the unit would be fogged). To save time and reduce cost, measurements could be made in a series of discrete steps, for example  $5$  or  $10^{\circ}\text{C}$  apart, with the intent of bracketing the dew point temperature. When fog is detected then the precise dew point temperature would be between the current temperature and the temperature of the previous at which no fog was induced. Repeated measurement in increasingly smaller steps would reveal the precise dew point temperature. After each measurement at which fogging occurs, the fog must be allowed to evaporate to re-establish the true water vapour content of the cavity gas. If the dew point temperature of all units in a set is increasing at a consistent rate, during subsequent measurements of other units it may be possible to skip some steps and arrive at the specific dew point temperature faster.

Test units should be free of direct solar gain when measured. The water capacity of desiccant(s) included in the spacer to adsorb water vapour in the cavity gas varies inversely with temperature. As temperatures fall, water vapour adsorption increases causing the cavity gas water vapour content and thus, the dew point temperature to decrease; as temperature increases, water desorbs from the desiccant(s) causing the cavity gas water vapour content and thus, the dew point temperature, to increase. Therefore, test units should be free of direct solar gain to avoid measurements of high dew point temperatures that would result in erroneous predictions of early time-to-fogging. In this regard, appropriate conditions for dew point temperature measurements are similar to those recommended for thermographic examination of building envelopes, such as described in ASTM C 1060, Appendix X2: there should be no direct solar radiation on surfaces to be inspected for three hours prior to the inspection for light frame construction (there is relatively little thermal mass in a window system) and wind conditions should also be fairly calm (not more than  $6.7\text{ m/s}$  or about  $24\text{ km/h}$ ) to avoid increasing heat loss and reducing unit temperatures. Practically, this requires dew point measurements to be made at night, preferably on overcast days with little wind. As much as possible, the conditions should be the same for all measurement periods.

### 3. DATA ANALYSIS & PREDICTION

Field dew point measurements should be recorded in tabular format in a computer spreadsheet, such as Microsoft Excel. For each group of units (ie. by elevation) and for the building as a whole, the average of measured dew point temperatures and one standard deviation colder and warmer than the average should be calculated and tabulated.

Once sets of measurements are available over at least three time periods, predictions can be calculated using the linear regression 'Forecast' function in Excel (or similar function in other spreadsheet programs) for the calculated average and if desired, one standard deviation warmer and colder than the mean.

In nominally cold climate countries such as Canada, fogging will usually occur on the inside surface of the outboard pane of glass. The surface temperature will be very close to ambient outdoor air temperature when no solar gain is present (in an insulating glass unit, most of the thermal resistance is provided by the exterior and interior surface air films, the cavity gas, and applied coatings). Thus, the amount of time between the last measurement period and the coincidence of prediction of future dew point temperature increase with a selected range of outdoor air temperatures would give the time-to-fogging. This time estimation can then be used for financial planning purposes.

## CMHC EXTERNAL RESEARCH PROGRAM STUDY

### TEST PROGRAM

In order to determine if time-to-fogging prediction by the Canadian method is accurate, a research program was devised and submitted to CMHC for funding under the External Research Program. A grant was approved in March 2004. Work began in April 2004, elevated temperature and water vapour exposure and cavity gas dew point temperature measurements were completed in February 2005, and reporting was completed in August 2005. The research report was published in January 2006.<sup>11</sup> The report is available via the internet through the CMHC website at [www.cmhc.ca](http://www.cmhc.ca).

Twelve standard test size insulating glass units were obtained by GRG from a local insulating glass unit manufacturer. Units were standard size for performance testing to current CGSB-12.8 and proposed ASTM E 2188 performance test standards, so that they could be fit into available test equipment at the Insulating Glass Laboratory at Bodycote Materials Testing Canada Inc. (IGL Bodycote). The research program consisted of:

- Initial examination of the units, including measurement of dew point temperature.
- Repeated cycles of exposure to elevated temperature and humidity to increase the rate of water vapour transmission into the cavity and thus increasing the cavity moisture content and



**Figure 3:** CGSB-12.8 High Humidity Chamber. A heated water spray cycles the air temperature between  $22 \pm 3^\circ\text{C}$  (lab conditions) to  $55 \pm 3^\circ\text{C}$  while maintaining 100% relative humidity. Elevated temperature increases the water vapour transmission rate of sealants and cycling the temperature increases and decreases unit cavity volume, stressing the sealants and in the case of a breach, creating a 'pumping' action that draws into the cavity warm, humid air from the chamber. File photo courtesy of Bodycote Materials Testing Canada Inc.

dew point temperature of the remaining nine units (Figure 3). Exposure was terminated when units were observed to be in a fogged condition upon removal from elevated temperature and humidity exposure.

- Between exposure cycles, measurement of the cavity gas dew point temperature with the units conditioned both sides at room temperature (standard laboratory conditions) and at simulated wintertime indoor / outdoor exposure.
- Visual examination of the units from time to time, to assess condition.
- Final visual examination of the units, tear-down to assess condition of concealed components.
- On-going and post-exposure analysis of measured dew point temperatures and development of prediction modelling techniques.
- Preparation of a detailed report describing rationale, method, observations, analysis, conclusions and recommendations for further study.

The intent of exposing one face of the units exposed to ‘outdoor’ conditions was to determine the effect of desiccant temperature on dew point temperature. The water vapour storage capacity of desiccants used for insulating glass units is known to increase with decreasing temperature. It was unknown how this might affect time-to-fogging estimates: for instance, if dew point measurements were made during cold weather, would the time-to-fogging estimate be longer, the same, or shorter than an estimate made during warmer weather? This was assessed by conditioning the test units at standard laboratory conditions as normally required by the performance test standards which coincidentally, were within the ‘normal’ summertime average daily maximum to minimum outdoor temperature range experienced in the Toronto area and thus simultaneously provided both indoor and summertime outdoor exposure, and then repeating measurements after conditioning the units with one face exposed to standard laboratory conditions and the other chilled by a freezer unit to about  $-12^{\circ}\text{C}$ , slightly below the ‘normal’ wintertime average daily maximum to minimum outdoor temperature range experienced in the Toronto area (Figure 4). ‘Normal’ temperature ranges were selected from available climate data on the Environment Canada website.

Dew point temperatures at summertime and wintertime conditions were measured with equipment normally used by IGL Bodycote in accordance with CGSB-12.8 (Figure 5). The field dew point test apparatus described in ASTM E 576 was not used. The normal IGL Bodycote



**Figure 4:** Simulated indoor / outdoor exposure apparatus designed by GRG and installed over the top of a low-temperature freezer at the Insulating Glass Laboratory at Bodycote Materials Testing Canada Inc.

The apparatus consists of a thermally-broken aluminum framed window mounted in a wood buck. Lights were installed in the freezer chest to enable viewing of fog during dew point measurements. A fan circulated air within the freezer chest to prevent stratification and to create a moving air film as would occur outdoors.

apparatus was capable of multiple simultaneous tests and thus was more time efficient. This equipment is similar to the field dew point apparatus used in the Norwegian study previously described and currently used in Europe.

The dew point temperatures of the test units as received were not measurable (ie. a 'no fog' condition, temperature less than  $-73^{\circ}\text{C}$ ). Despite elevated temperature and humidity exposure, dew point temperatures remained below detectable values after 15 weeks. With a funding deadline approaching, it was decided to accelerate the rate of dew point temperature increase by breaching the perimeter seal. In the high humidity chamber, both temperature and humidity are increased above laboratory conditions; elevated temperature would increase the cavity volume by about 10%. Normally, this would result in increased pressure within the unit but the seal breach openings would allow for escape of cavity gas into the chamber; upon cooling within the chamber, humidified air would enter the unit. This exchange would move water vapour into the unit cavities at a much faster rate than by diffusion through the perimeter sealants.

As a precaution, three units were left with the seal intact in case the rate of dew point temperature rise was too fast to provide sufficient sets of measurements to use for prediction modelling. Openings in the other six units were increased in size over several measurement periods until a general increase in dew point temperature was detected, then the openings were left untouched for the remainder of the test program. In total, ten sets of dew point temperature measurements were obtained for prediction modelling.

## DATA ANALYSIS AND PREDICTION

### EFFECT OF DESICCANT TEMPERATURE

The effect of temperature on desiccant suppression of the cavity gas fill dew point temperature was assessed by calculating and plotting the average dew point temperatures measured at simulated indoor / outdoor summer conditions (ambient laboratory) and simulated indoor / outdoor winter conditions (one side exposed to the freezer) against time (Figure 6). The plot revealed that dew point temperatures at summer conditions were about  $25^{\circ}\text{C}$  warmer than dew point temperatures measured at winter conditions. A similar temperature / dew point suppression relationship was identified in the NBRI study for units incorporating desiccant, confirming that the condition occurs during actual indoor / outdoor exposure conditions.

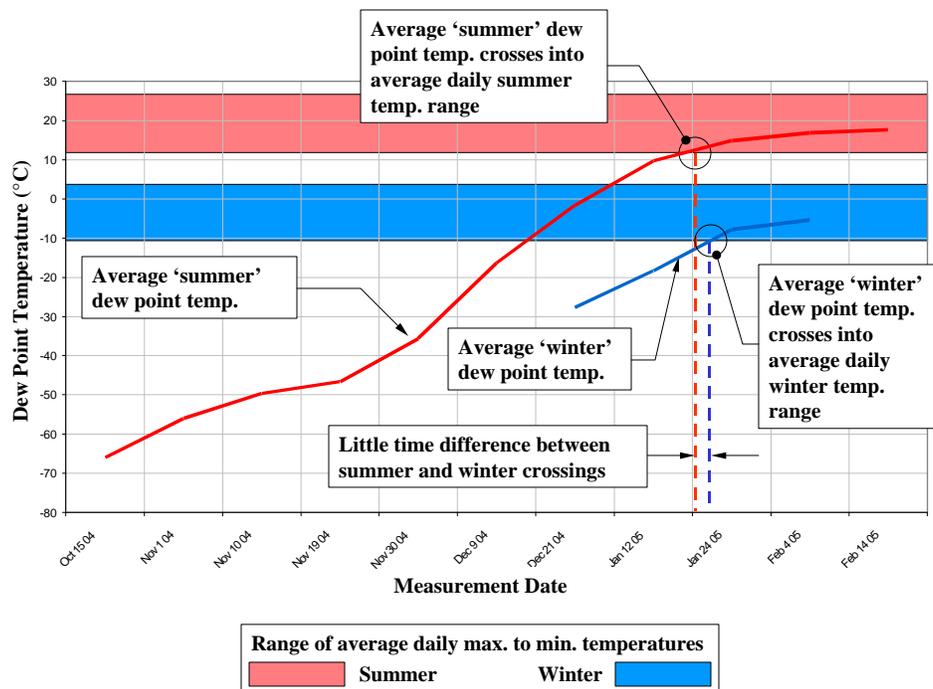
The primary function of the desiccant within an insulating glass unit is to reduce the dew point temperature of the cavity gas fill sufficiently so that, under 'normal' weather conditions, condensation on glass surfaces within the cavity does not occur, obscuring vision. This is accomplished by the physical adsorption ('physisorption') of water vapour onto the surface of the



**Figure 5:** Dew point test apparatus. 'Dry ice' (solidified carbon dioxide) is being added to a metal cylinder to chill an ethyl alcohol filled metal container. The bottom of the container is in direct contact with the upper pane upper pane of the insulating glass unit below. If the temperature of the alcohol / dry ice mixture is reduced below the dew point temperature of the unit cavity gas fill, condensation or frost will be visible below the container when it is removed. File photo courtesy of the Insulating Glass Laboratory at Bodycote Materials Testing Canada Inc.

desiccant. Water vapour molecules come into close proximity with the desiccant through constant motion within the cavity gas and are attracted to, and held on to, the surface of the desiccant by relatively weak, short-range electrostatic forces ('van der Waals' forces). The attraction occurs because the shape of water vapour molecules gives rise to relatively positive and negative charged regions that are attracted to oppositely charged sites on the surface of the desiccant. Those charged sites arise from unsatisfied chemical bond energy of molecules at the surface of the desiccant. When the energy of a water vapour molecule is reduced, such as through a reduction in temperature, so that it is less than the attractive force between it and a charged site on the desiccant surface, the molecule is adsorbed. Heat (energy) is liberated, mostly due to the change in phase of water molecules from vapour to liquid ('latent heat of vapourization') and to a lesser amount, due to the resolution of unsatisfied surface energies ('heat of adsorption'). The liberated heat is dissipated into the desiccant and the cavity gas. Adsorbed water molecules do not undergo significant physical change during adsorption so that the process can be readily reversed ('desorption') by adding back to the water vapour and desiccant the energy (heat) that was liberated and dissipated during adsorption.<sup>13, 14, 15</sup>

In the case of the test units, chilling the units from 'summer' (lab) condition to 'winter' (lab / freezer exposure) conditions removed energy (heat) from water vapour in the cavity gas fill, such that adsorption onto the desiccant increased. The water vapour content and thus, the dew point temperature of the cavity gas fill were reduced.

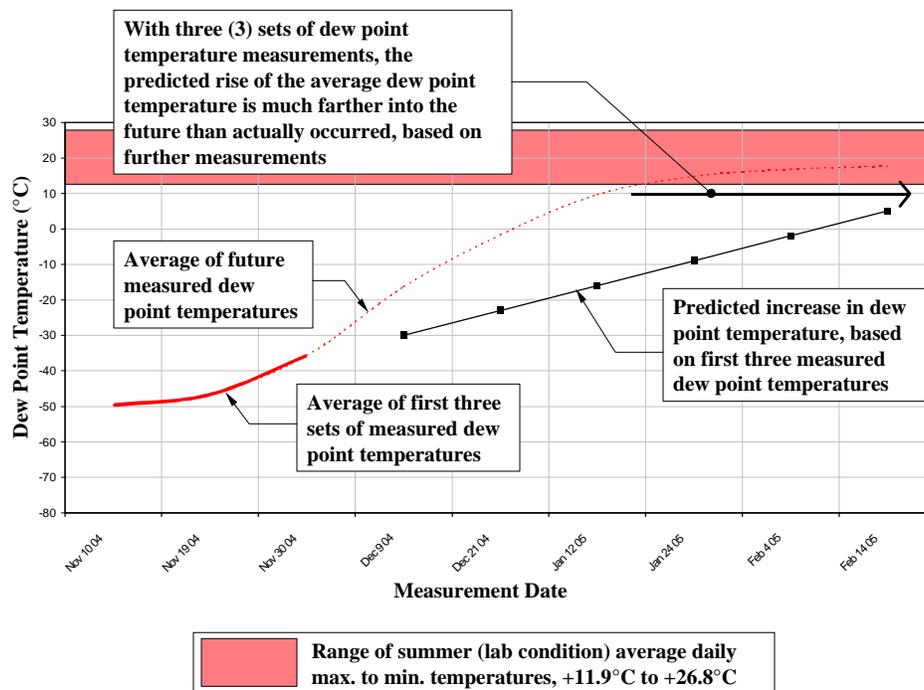


**Figure 6:** Composite plot of average 'summer' (lab condition) and 'winter' (simulated outdoor exposure) dew point temperatures and average daily maximum to minimum temperature ranges for Toronto, Ontario. Note that the average 'summer' and 'winter' dew point temperatures cross into the corresponding outdoor temperatures at about the same time.

Adding the 'normal' ranges of average daily maximum to minimum ambient outdoor air temperatures for summer and winter for Toronto to the plot revealed that the average summer and winter dew point temperature curves intersected the corresponding temperature ranges at about the same time (Figure 6). From this, it can be seen that monitoring dew point temperatures under summer conditions allows for earlier prediction of time-to-fogging and thus, more advance notice to adjust a capital repair and replacement fund to ensure that adequate funds for replacement are available.

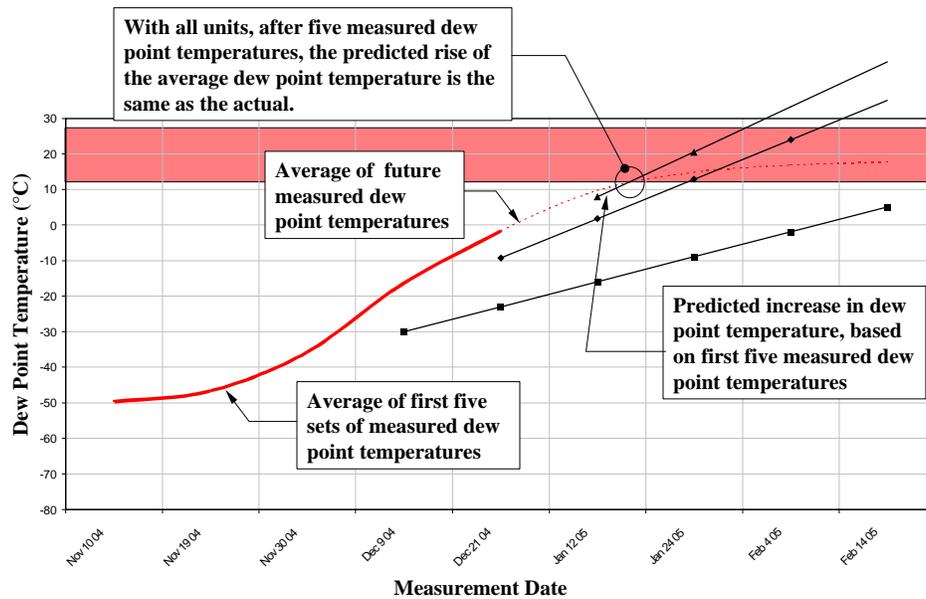
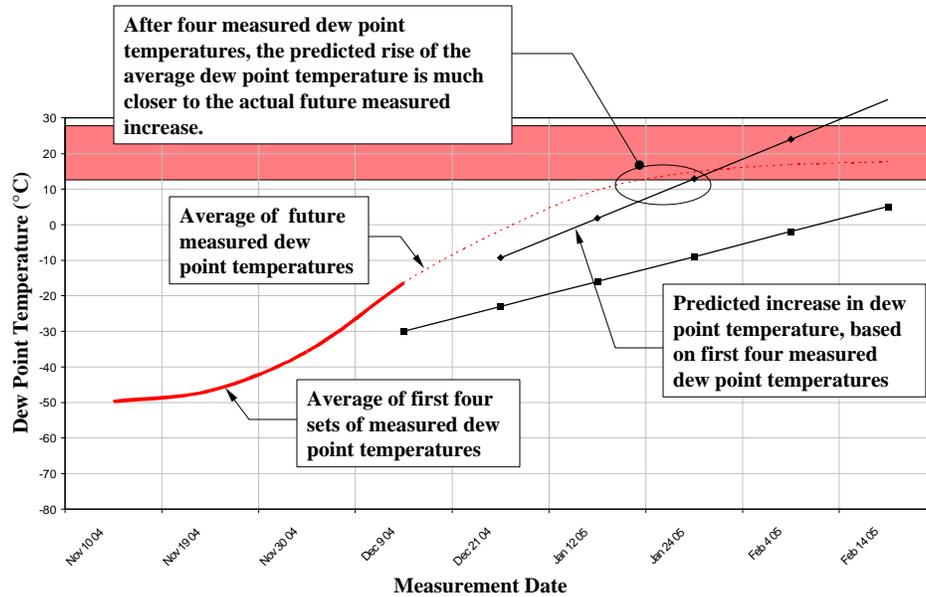
#### TRIAL PREDICTIONS

For reasons already discussed, trial predictions were made using the dew point temperatures measured at summer conditions. Predictions were based on the first three, four and five measured sets of dew point temperatures, such as would occur in a real-life situation as dew point temperature data is accumulated over time. The method previously described was follows. Detailed results are included in the CMHC study and illustrated in the following series of graphs (Figures 7, 8 and 9):



**Figure 7:** First prediction of average dew point temperature increase at 'summer' (lab) conditions for the units in the CMHC study, together with the 'normal' average daily maximum to minimum temperature range for Toronto, Ontario.

The first prediction (Figure 7) is not very good but the results of the second and third predictions (Figures 8 and 9) are in very good agreement with the actual test data (red dotted line). Clearly, accuracy improves a more time periods of measurement data are accumulated.



Range of summer (lab condition) average daily max. to min. temperatures, +11.9°C to +26.8°C

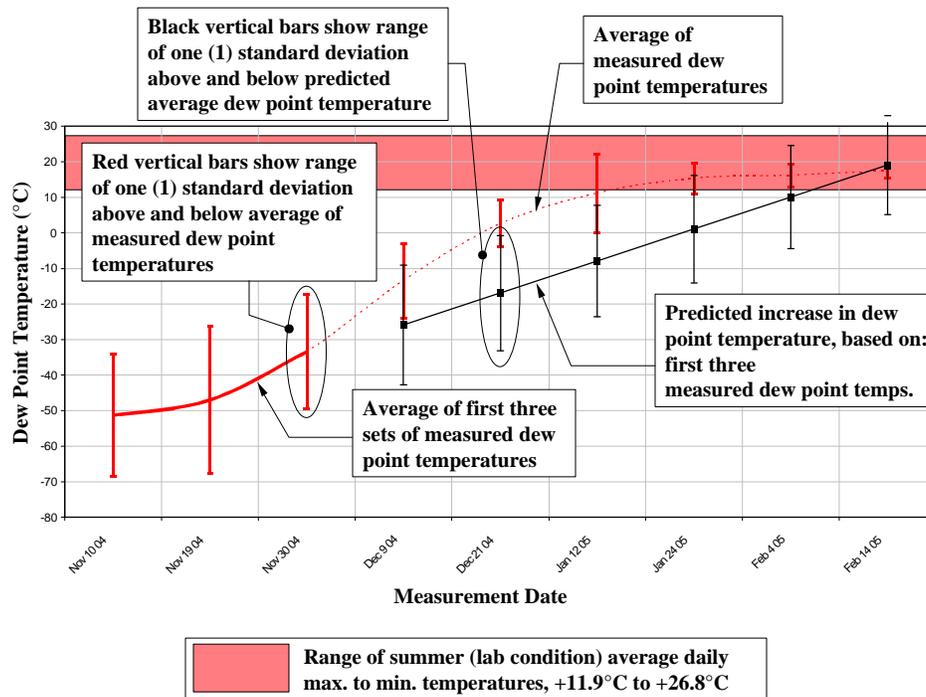
**Figures 8 and 9:** Second and third predictions of average dew point temperature increase at ‘summer’ (lab) conditions for the units in the CMHC study, together with the ‘normal’ average daily maximum to minimum temperature range for Toronto, Ontario.

#### LOOKING BEYOND THE AVERAGE

It is reasonable to expect that in a population of insulating glass units and in a randomly selected sample of the population, there will be some variation in dew point temperatures about the average. Thus, for some units the time-to-fogging will be shorter than the average and for others, it will be longer. Funds should be available to replace some portion of the shorter time-to-

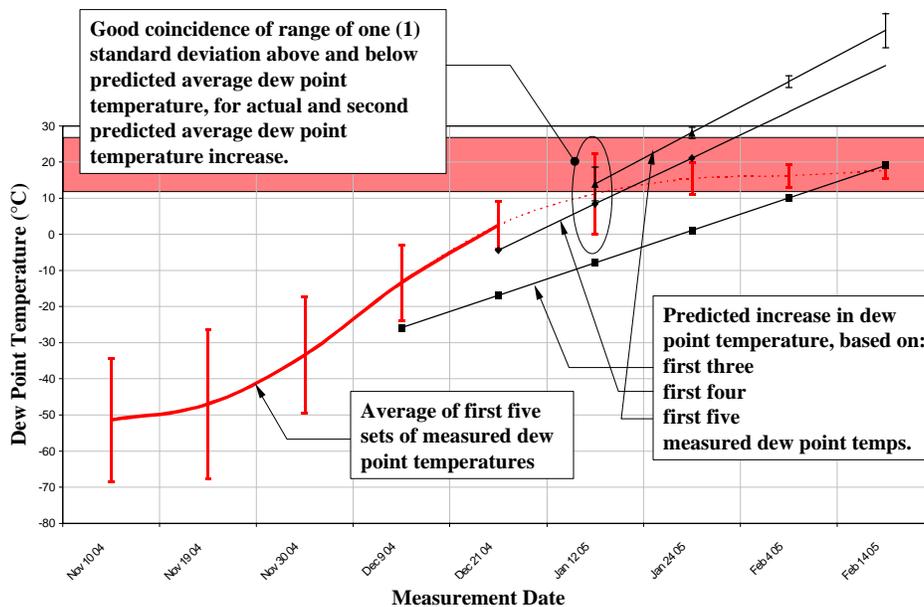
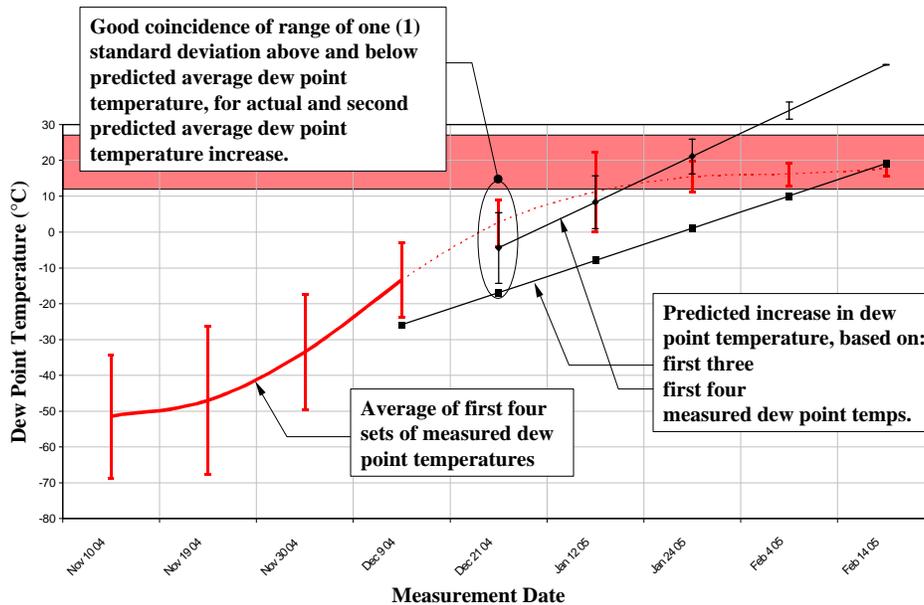
fogging units; depending on the size of the population(s) tracked, this could be significant and affect capital repair and replacement reserve planning, particularly if other significant expenditures are expected to occur at about the same time. Similarly, if the number of units with longer time-to-fogging is significant, less aggressive fund accumulation may be required.

Assuming that a given population of units is ‘normal,’ units one standard deviation warmer and colder than the mean would include about 68% of the units. The time-to-fogging of this broader range can be predicted in the same manner as for the mean and plotted, by calculating the standard deviation above and below the mean for each measurement period and predicting future values using the ‘Forecast’ function in Microsoft Excel (or other spreadsheet program), an plotting against the range of ‘normal’ average daily maximum to minimum summertime outdoor air temperatures (Figures 10, 11 and 12).



**Figure 10:** First prediction of average dew point temperature with ‘error bars’ added to show the range of one (1) standard deviation warmer and colder than the mean.

For units in this study, there was not much benefit to plotting one standard deviation warmer and colder than the average for the first prediction since the that prediction was inaccurate (Figure 10). However, for the second and third predictions (Figures 11 and 12) there is good coincidence between the predicted values of one standard deviation warmer and colder than the predicted average and the values calculated from actual data; thus, it is reasonable to expect that it should be possible to identify units that might fog earlier than the average and adjust financial planning to suit.



Range of summer (lab condition) average daily max. to min. temperatures, +11.9°C to +26.8°C

**Figures 11 and 12:** Second and third predictions of average dew point temperature with 'error bars' added to show the range of one (1) standard deviation warmer and colder than the mean.

It is possible to predict more than one standard deviation in advance of the average. Whether or not this is necessary depends on the financial sensitivity of the building owner or sometimes, on legislated requirements. For example, in the case of reserve fund plans for condominium corporations in Ontario, all foreseeable capital reserve and replacement items greater than \$500

must be included in the plan which would likely require predicting at least three standard deviations in advance of the mean. This is a severe requirement because the cost of replacement of a single insulating glass unit is about this amount. Other, more reasonable, limits may be desirable by a building owner and should be established at the beginning of the monitoring program so that an appropriate point in advance of the mean can be predicted and tracked over time. Note that lower limits (for instance, one standard deviation in advance of the average, as shown) would require the owner to be able to fund some replacements or repairs from operating funds. Knowing the number of units and their value that is being tracked and considered in the reserve fund plan, predictions of the value of the remainder could be made and sufficient funds kept on hand.

## **SUMMARY**

The trend in modern architecture to enclosing more of the building envelope with glazing – windows, window walls, curtain walls, sloped glazing and skylights – has given rise to greater capital repair and replacement needs for building owners. Whereas traditional materials such as stone, brick or precast concrete could be expected to last the life of the building with relatively minor costs for repair (if constructed properly), insulating glass units incorporated in glazing systems have finite service lives and will need to be replaced, possibly several times in the life of a building. The costs can be significant and should be anticipated and funded with care through carefully calculated capital repair and replacement reserves.

Visual review of insulating glass units reveals very little information that is of use in assessing timing for replacement units unless fogging is occurring – in which case, replacement needs are immediate. Given that replacement costs can be significant, it would be prudent for building owners to assess on-going performance so that adequate funds for replacement are available as needed. Thus a monitoring and prediction of time to replacement (time-to-fogging) methodology is of value. Such a program has been proposed and validated by a laboratory study, as described in this paper.

The method has limitations. The cooling medium most often used, solidified carbon dioxide ('dry ice') allows detection of the dew point temperature of the cavity gas of insulating glass units down to about  $-73^{\circ}\text{C}$ . Generally, the dew point temperature of new insulating glass units is colder and many years of service may be required until it becomes warmer, allowing a monitoring program to begin. Thus, in the early life of a building or for an existing building following completion of an insulating glass replacement program, a life span must be assumed, based on experience, for capital reserve and replacement fund planning purposes. Periodically, trials should be made to check for measurable dew point temperatures so that as soon as possible, a monitoring and prediction program can be initiated. Once initiated, at least three sets of measurements over regular time periods are needed to calculate a future rate of increase. Calculations may be carried out using available computer spreadsheet software with a prediction function, such as 'Forecast' in Microsoft Excel. When combined with local weather records, time-to-fogging predictions can be made. Accuracy will be increased if further sets of dew point measurements are made.

Despite this limitation, as noted, the monitoring and prediction methodology described in this paper has proven that an accurate estimate of time-to-fogging can be made. It is recommended that the methodology described in this report be put into service to assist building owners to more accurately plan for capital replacements or repairs.

## ACKNOWLEDGEMENTS

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