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BY

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PERFORMANCE OF SEALED DOUBLE-GLAZING UNITS

By A. G. Wilson* and K. R. Solvason**

Double windows are widely used in Canada to reduce heat transmission through glass areas, and to permit a higher relative humidity than is possible with single glass without excessive condensation on inside glass surfaces. In the last few years there has been a large increase in the use of sealed double-glazing units and this has introduced new problems in assessing durability and performance. A potential problem with most available types of conventional double windows is condensation on the inside surface of the outer glass. It is possible to limit such condensation so that it does not become objectionable by providing an unusually tight inner glazing assembly and some venting of the air space between panes to outside (1). Cleaning of the glass surfaces facing the air space is required at intervals depending upon the amount of dirt carried into the space between panes in the venting process and on the amount of "scumming" of the glass surfaces. The latter refers to deposition on the surface of sodium salts formed in the normal "corrosion" of soda-lime glass. These salts are deposited and concentrated on the surface by a leaching process when the surfaces are wetted and dried. Thus such double window units must be designed to provide convenient access to all surfaces for cleaning at intervals if the units are to give satisfactory service.

In sealed double-glazing units the objective is to seal hermetically the space between panes and to maintain the dew point temperature of the air space sufficiently low to prevent condensation on inaccessible surfaces and thus prevent "scumming". If this can be achieved it is anticipated that inaccessible glass surfaces will remain clear. The need for cleaning is limited, then, to the two exposed glass surfaces. A hermetic seal is extremely difficult to achieve, however, and even more difficult to maintain under normal conditions of exposure. The seal is subjected to continual stressing by natural forces and components are subject to aging. If failure of the seal occurs the moisture content of the air space will increase until ultimately widespread condensation occurs and soiling of inaccessible glass surfaces results. Under adverse conditions liquid water may be drawn into the units through openings in the seal to provide dramatic evidence of failure. The units can also fail by breakage from several causes. When failures develop, the units must be replaced, and since they are relatively expensive it is essential to minimize failures during the life of the building. Widespread premature failure, as has occurred in a number of instances in recent years, involves serious financial loss.

In order to provide the consumer with some protection against the financial loss involved in failure it has been the practice of manufacturers of sealed units to give a five-year warranty. Such a warranty, however, has a number of limitations, the most obvious being that five years is a relatively short period in the life of most buildings. The proposition that units which last five years are likely to last twenty-five has little to support it in this case. A second limitation is the difficulty of defining failure. When the glass breaks, or if the units become filled with water failure is obvious. There are various degrees of condensation and

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soiling and other types of failure which are not specified, however, and which may not be recognized by the manufacturer as "failure". Finally, the warranty is of little value if the manufacturer has gone out of business, something which has occurred several times in recent years. Some protection against this possibility can be obtained by requiring that the manufacturer provide a bond. The number of companies that can obtain such bonds at this time is very limited, however.

In view of the extensive use in Canada of sealed double-glazing units, the Division of Building Research, NRC, has been conducting a laboratory program on the evaluation of these units. The program was initiated at the request of Central Mortgage and Housing Corporation for assistance in establishing a sound basis for determining the acceptability of such units for use in houses financed under the terms of the National Housing Act. The early phases of this work have been described (2); this present paper reviews the causes of seal failure and breakage and presents a summary of the results of recent laboratory studies.

Description of Sealed Glazing Units

All hermetically sealed double-glazing units require some method of spacing and sealing the glass at the edges and of providing a dry atmosphere between panes. In one well-known proprietary design the spacer is of lead and the glass is sealed to the lead by a special soldering technique. The space between panes is purged with dry gas before the final sealing. Another type of unit produced by at least two major manufacturers employs an all-glass edge with the space between panes dried by purging before final sealing. This construction apparently requires high volume production in order to achieve an economic unit. The glass seal results in a relatively rigid edge construction. The lead seal is less rigid due to the flexibility of the spacer.

A third method of construction, which has been employed by at least one major manufacturer for several years, has been adopted by the majority of manufacturers who have recently entered the market. This consists of a hollow spacer, containing desiccant, sealed to the glass with an organic sealant. Drying of the air space is achieved with the desiccant which is connected with the air space through holes or joints in the spacer. Edges of the units may, or may not, be protected by metal channel or tape. There is considerable variation in the design of spacer, choice of sealant, details of edge protection and corner construction. There are also large differences in the equipment and techniques used in assembling the units and in control of quality.

Spacer materials used with organic sealants include galvanized and stainless steel, aluminum alloy, and polyvinyl chloride. In almost all units these are hollow and contain the desiccant. In principle the thermal coefficient of expansion of the spacer should be as close as possible to that of glass to minimize the tendency for differential movement between the two elements. Any tendency for differential movement is reflected in a stretch or flow of the sealant or stressing of the glass. The shape of spacers in use is quite varied; some have simple circular or box sections, others are more complex.

The basic objective of the sealing system is to prevent interchange of air, water vapour or liquid water between the air space and surrounding atmosphere. The primary sealant must therefore have a low water vapour permeability. It must also have excellent adhesion to both spacer and glass and must maintain this adhesion under all exposure conditions so that cracks or openings do not develop at interfaces. In some designs the primary sealant is also expected to hold the unit together, that is, to provide compressive and tensile strength. In others the unit is held together structurally by a metal channel surround (stainless steel or aluminum). A secondary sealant may be used to provide the necessary strength and bond with the glass and spacer, in which case the metal channel surrounds serve principally as edge protection for the glass.

There has been much activity in the development of organic sealants in recent years and manufacturers are continually putting new products on the market, many intended for curtain wall jointing systems. There has been no long-term field experience with most of these and reliance must then be placed on laboratory measurements of physical properties in selecting sealants for various applications. Probably the most difficult and critical application is in sealed glazing units. The majority of sealants now in use for this purpose appear to be either polysulphide, butyl or other synthetic rubber-base mastics, with various additives. Epoxy resins have also been used. These broad groups encompass compounds having a wide range of properties. Compounds must be carefully formulated to provide properties required for sealed glazing units. The properties required are also a function of the over-all design of the edge construction and fabrication methods. It is not surprising that a number of sealed glazing manufacturers have changed from one sealant formulation to another several times in a two- or three-year period in attempts to find more satisfactory sealing systems.

Factors Involved in Failures

Stresses leading to seal failures and glass breakage are imposed on double-glazing units in several ways: by pressure differences between the enclosed air space and surrounding air due to temperature and barometric pressure changes; by differential expansion or contraction of components caused by unequal thermal expansion coefficients and differential temperatures; by wind pressures; and in some cases by forces which develop due to faulty installation.

Units are usually sealed in the plant at temperatures of about 70°F. Some attempt may be made to control the pressure in the unit prior to sealing; for example, sealing may be completed only when the barometric pressure is within a specified range. Where units are to be used at an elevation greatly different from that where manufactured, final sealing may be completed after shipment. In service, units may be exposed on one side to temperatures of -30°F or lower, corresponding to a mean air space temperature of less than 15°F. A change in mean temperature of the units from 70°F to 15°F can produce a pressure change within them which is equivalent to a rise in external pressure of the air of about 220 lb per sq ft or 3.0 in. of mercury. During shipping and installation in winter units may be cooled on both sides to outdoor temperature. A mean temperature of -30°F is equivalent in terms of pressure differences to a rise in external pressure of 385 lb per sq ft. Similarly windows exposed to solar radiation may have mean temperatures in summer from 90°F to 135°F depending on the absorption of the glass, with correspondingly large increases in internal pressure. The daily variation in mean temperature of the units in either summer or winter may be from 20 to 65°F. The pressure differences between the sealed space and outside will be augmented by normal barometric pressure changes of ± 1 in. of mercury.

The actual pressure difference between the space and surrounding air will be less than the equivalent external pressure changes referred to above since the volume of the air space will change due to deflection of the glass. The deflections will increase and pressure differences decrease as the area of the unit is increased; conversely there will be smaller deflections and larger pressure differences as the thickness of the glass is increased. Because both deflection and pressure difference increase with increasing air space thickness, air space thicknesses are usually limited to a maximum of about ½ in. The minimum practical air space thickness is about 3/16 in., because the insulating value of the units falls off sharply with decreasing thickness below ½ in.

If the air space and ambient pressures are unequal at the mid-point of the temperature range through which the unit fluctuates, the maximum pressure differences and glass deflections will be correspondingly greater. In this way small seal leaks can contribute to increased pressure differences and to glass breakage. If, for instance, the pressure equalizes at one of the temperature extremes due to a seal leak which then heals, an unusually high pressure difference will occur at the other temperature extreme. This can result, for example, in the two panes contracting at the centre in cold weather. This can also occur if units are too large relative to the thickness of the air space.

Pressure differences tend to force the glass against the spacer or to pull it away and produce compression or tensile forces in the seal material depending on whether the internal pressure is lower or higher than ambient. On a 4- by 6-ft unit, for example, this force will be quite substantial, perhaps from 100 to 150 lb per ft of spacer. There is also a tendency for the glass to rock or pivot on the spacer when the centre deflects. With very rigid edge constructions the glass must bend in a reverse curve, increasing glass stress and the tendency to crack. With more flexible edge constructions the glass edges bend in a simpler curve with less stress in the glass, but the rocking motion tends to separate the glass from the seal and the seal material must be able to withstand this movement without failure.

The coefficient of thermal expansion of glass is approximately 4.5×10^{-6} in. per in. per degree F. In a 72-in. length a temperature difference of 40F degrees between lights produces a differential dimensional change of 0.013 in. This differential movement between inner and outer panes may induce significant glass stress if the edge construction is rigid, and must be absorbed by seal movement in non-rigid constructions. If the thermal expansion coefficient of the spacer materials is much different from that of the glass considerable stress can be applied to the seal. Aluminum has a coefficient of about 14×10^{-6} per degree F. If the unit undergoes a temperature change of 50F degrees the differential dimensional change of the glass and spacer is about 0.035 in. in a 72-in. length. With soft sealants that flow under stress the differential movement between glass and spacer at the corners would amount to 0.017 in. The thermal coefficient for ordinary steel is about 6.6×10^{-6} per degree F, which results in a corresponding differential movement at the corners of 0.004 in. Polyvinyl chloride spacers have thermal coefficients in the range of 28 to 84×10^{-6} per degree F. The corresponding differential movement at the corners for the above example is 0.043 to 0.15 in. which, if unrestrained, would probably lead to seal damage.

If the seal material is elastic the differential movement must be taken up by shear in the sealant, or strain in the spacer, depending upon the relative strength and stiffness of the spacer section and sealant. With a high strength spacer, a low strength sealant will tend to fail in shear; a high strength sealant will tend to break the glass. Thus, if the thermal coefficients of spacer and glass are significantly different, the spacer section must be relatively weak and the adhesion of the sealant to the glass and spacer sufficient so that the spacer will follow the changes in dimension of the glass. Temperature differences between the glass and spacer, as will often occur in practice, may also cause a shearing action between glass and spacer, even when the coefficients of thermal expansion are similar.

Wind loads will stress both the glass and the seal. The magnitude of pressure differences due to wind loads, except perhaps at the design wind load conditions, is very small compared to the pressure differences caused by thermal expansion and contraction of the enclosed air and barometric changes. Wind can produce many more cycles of glass deflection under gusty wind conditions, however, than the temperature and barometer effects and this glass deflection will stress the seal.

Differential temperatures on the glass are a major factor contributing to glass breakage, particularly with heat-absorbing glass. When a window is suddenly exposed to solar radiation the glass temperature may rise very quickly, at least over its central portion. The edge temperatures may rise more slowly, partly because the edge is shaded from radiation and also because of the relatively large heat capacity of the frame. These temperature differentials produce high tensile stresses in the glass near the edge and compressive stresses in the centre. The strength of the glass is usually sufficient to withstand the stress produced in clear glass by the temperature differentials alone, but if the glass is already stressed from other causes, the added thermal stress will often cause breakage. Partial shading of glass can produce similar effects. Edge imperfections increase the likelihood of breakage due to stress concentrations.

On windows exposed to solar radiation the depth of edge recess should be kept to the minimum required to handle wind loads, about 3/8 in. to minimize thermal stresses. The thermal capacity of the frame should be as low as possible to minimize its heat storage effect. It is also advantageous if the frame members have a high radiation absorption coefficient so that the rate of temperature rise will be more nearly equal to that of the glass when both are exposed to solar radiation.

Correct installation practices are extremely important to the successful performance of sealed glazing units. Bedding compounds which are chemically incompatible with the sealing material can cause failure. If spaces develop between the bedding material and the glazing units damage to the seal can occur from water and frost action. The bedding materials must remain sufficiently resilient to accommodate differential movement between the frame and the unit.

It is common practice to support units of moderate width on two setting blocks located in from each corner one-quarter the width of the unit. While glass breaks sometimes originate at this location due to the resulting stresses, attempts to get uniform bearing of the bottom edge often lead to single-point loading and greater stresses. Care must be taken to obtain uniform bearing on the blocks and particularly to see that both panes are supported; otherwise one pane may be carried in shear on the seal and seal failure may occur due to differential movement between the two panes. Very wide units are usually supported at three points. Here it is important that the bottom frame member does not distort and lead to single-point support.

In addition to mechanical failures induced by stresses and deformations, units can fail due to deterioration of the sealant with age. In addition to the loss of desirable physical properties, which may result in leaks or excessive water vapour diffusion, vapours which will soil the glass may be evolved from some sealants on heating or exposure to ultra-violet radiation.

Dew Point Temperature and Seal Leakage

The moisture condition of the air space of sealed double-glazing units can be defined in terms of its dew point temperature. Moisture transferred to the space is evident as a rise in dew point. For units without desiccant the rise in dew point is a function only of the volume of the space and the amount of water transferred to it. For units containing desiccant the rise in dew point depends also on the amount of desiccant, its moisture content and temperature. The moisture isotherms for silica gel shown in Fig. 1 indicate the increase in moisture content required for a given increase in dew point temperature. It will be noted that much less moisture increase is required to change the dew point temperature from -60°F to 0°F than is required to change it from 0°F to 30°F; also, for a given desiccant moisture content, the dew point temperature over the desiccant decreases as the temperature decreases. These curves are plotted from reference data [3] in order to demonstrate this characteristic of desiccants and do not apply precisely to all types.

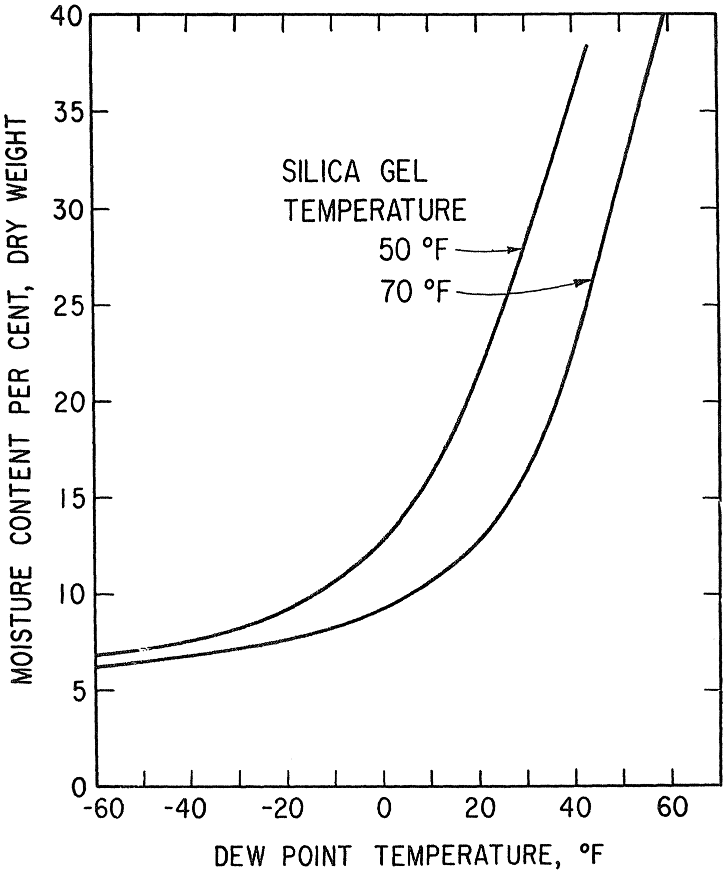

FIGURE 1

Moisture content vs dew point temperature for silica gel

It is difficult to establish the minimum values of air space dew point temperature at which problems of condensation and soiling occur in practice. Objectionable condensation will probably occur when dew point temperatures are above 30°F, and this figure has been used arbitrarily as a criterion in the laboratory tests to date. The decrease in the dew point temperature of air in contact with the desiccant as the temperature decreases, reduces the possibility of condensation. Laboratory observations indicate, however, that noticeable condensation can occur in units with measured dew points of 0°F when the unit is cooled rapidly following a period of heating. In this case there is insufficient time for the air space to come into equilibrium with the desiccant; similar occurrences can be expected in practice.

Moisture can be transferred to the air space of sealed double-glazing units by diffusion of water vapour through the sealing materials and, if seal leaks exist, by air flow due to the pumping action induced by temperature and barometric pressure changes. The amount transferred by diffusion depends on the water vapour permeability of the sealant, the length of path through the sealant and its cross-sectional area, and the vapour pressure difference. There is a wide variation in the water vapour permeability coefficients of sealant formulations in use. Calculations indicate that if no desiccant were used excessive dew point rise due to water vapour diffusion would occur with many of these in periods of only a few weeks, even with initial dew points of -60F or lower. With spacers filled with desiccant, moisture transfer by diffusion alone is unlikely to lead to failure of the unit within a five-year period with most types of sealants in use, but in some instances is likely to lead to failure well within the anticipated service life of the building.

The amount of moisture that can be transferred through seal leaks by pumping action will often be more significant than that transferred by diffusion. Consider, for example, a 4- by 6-ft. unit with 1/2-in. air space, containing a leak through which air could flow under pressure. If the unit were cycled daily through 30°F and interchanged air with a room at approximately 70°F and 50 per cent relative humidity, only 11 days would be required to raise the dew point from -60°F to 30°F without desiccant. If the unit contained 1/4 lb of silica gel, about three years would be required for an equivalent dew point rise, although the dew point would rise to 0°F in less than one year.

It will be clear, therefore, that seal leaks on units without desiccant will become apparent very quickly. On the other hand, leaks in units containing desiccant may not be noticed for several years unless there is entry of liquid water. It is certain, however, that leaky units will eventually fail, sometimes within a five-year period, sometimes later. Furthermore, the chances of leaks developing will increase with time, under repeated stressing and aging of the seal. When water is permitted to collect at the edge of a unit, it is very likely to be drawn into the unit through small leaks, resulting in early failure. The possibility of this is greatest at the lower edge of the unit. Bedding compound may provide some initial protection but the chances of water entry increase as the bedding deteriorates with age and with strain due to wind loads and building movements.

Test Program

The studies on sealed double-glazing units being conducted by the Division of Building Research have two principal objectives: to develop acceptable laboratory test methods and criteria for evaluation of the degree of sealing provided by hermetically sealed units and ability to maintain a seal during service life; and to provide manufacturers with information that can be used as a basis of acceptance by Central Mortgage and Housing Corporation (CMHC). The present test program involves three principal stages. For these tests 18 specimens, each 14 in. by 20 in., are required. The selection of this size of unit is arbitrary and has been discussed[2]. The first stage of testing involves the measurement of initial dew point temperatures and seal leakage tests in a vacuum chamber on all 18 specimens as received. The dew point apparatus is shown in Fig. 2 and is a modification of one described previously[2].

The apparatus, containing acetone cooled by dry ice, is held in contact with the glass for 1½ minutes and then removed to observe if condensation or frost has formed on the glass surface adjacent to the air space. This procedure is continued, with successive lowering of the acetone temperature until condensation or frost is visible. The acetone temperature, measured by an alcohol-in-glass thermometer, required to produce condensation or frost is recorded as the dew point temperature of the unit.

The test for seal leakage consists of lowering the air pressure surrounding the unit and observing the glass deflection. The units are mounted on a rack in a vacuum chamber with a dial indicator in contact at the centre of the glass on each side, so that the deflection of each pane can be measured within ± 0.001 in. The dial indicator readings are initially adjusted to zero and the chamber pressure lowered to 27.8 in. of mercury which corresponds to the pressure at approximately 2000 ft. altitude. This provides a pressure change outside the unit of about 2.1 in. of mercury or 148 lb per sq ft and has essentially the same pressure effect on the unit as raising its average temperature from 70° to 107°F.

The readings of all dial indicators are recorded between 30 and 60 seconds after

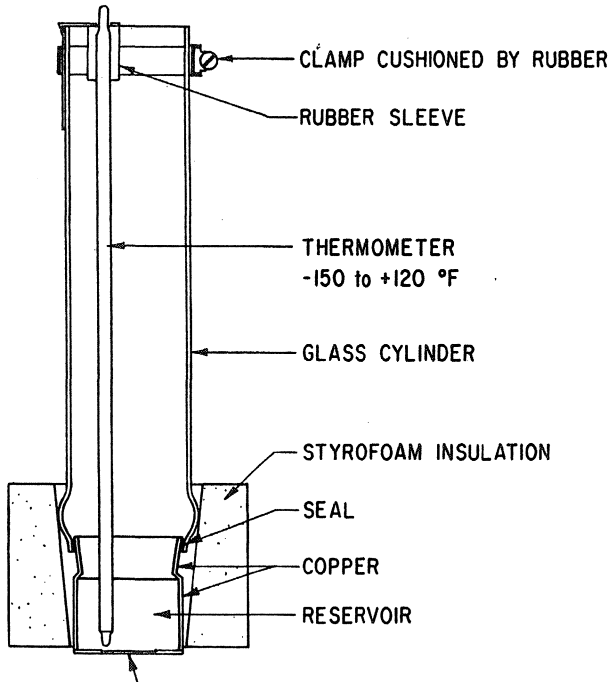

FIGURE 2
Apparatus for window dew point measurement

the pressure is lowered, and observed at frequent intervals to note any change in deflection. Final readings are taken after 2½ hr. The chamber is then returned to atmospheric pressure and the dial indicator readings again recorded. A sustained deflection at the lower pressure which decreases to zero upon equalization of pressure indicates no apparent leakage. No initial deflection indicates a leak so large that the air pressure in the unit very quickly reaches equilibrium with that outside the unit. An initial deflection decreasing with time of exposure to the lowered pressure indicates a smaller seal leakage. An initial but slowly increasing deflection indicates creep or stretching of the seal material.

The present CMHC requirement calls for dew points not in excess of 30°F and no loss of deflection (evidence of leakage) in the vacuum chamber. One failure in 18 specimens has been allowed on the assumption that quality control cannot be perfect.

The second stage of the testing consists of measuring dew point and vacuum chamber deflection on 12 of the 18 specimens exposed to laboratory weathering. These tests are carried out only on those sets that have passed the initial tests. The laboratory weathering apparatus in use at present is shown in Figs. 3 and 4 and has been described(2). One surface of units under test is exposed in the laboratory at 73°F and 50 per cent relative humidity, while the other surface is exposed to the laboratory weathering cycle conditions. The units are installed in the laboratory weathering apparatus without glazing compound so that the edges are exposed to weathering conditions. They are mounted so that no stress is induced in the units by the method of fastening. The weathering cycle consists of heating to 120°F for 1 hr 50 min, cooling to 110°F for 10 min, water spraying at 75°F for 5 min, draining at 75°F for 15 min, and cooling to -20°F for 1 hr 40 min, the total

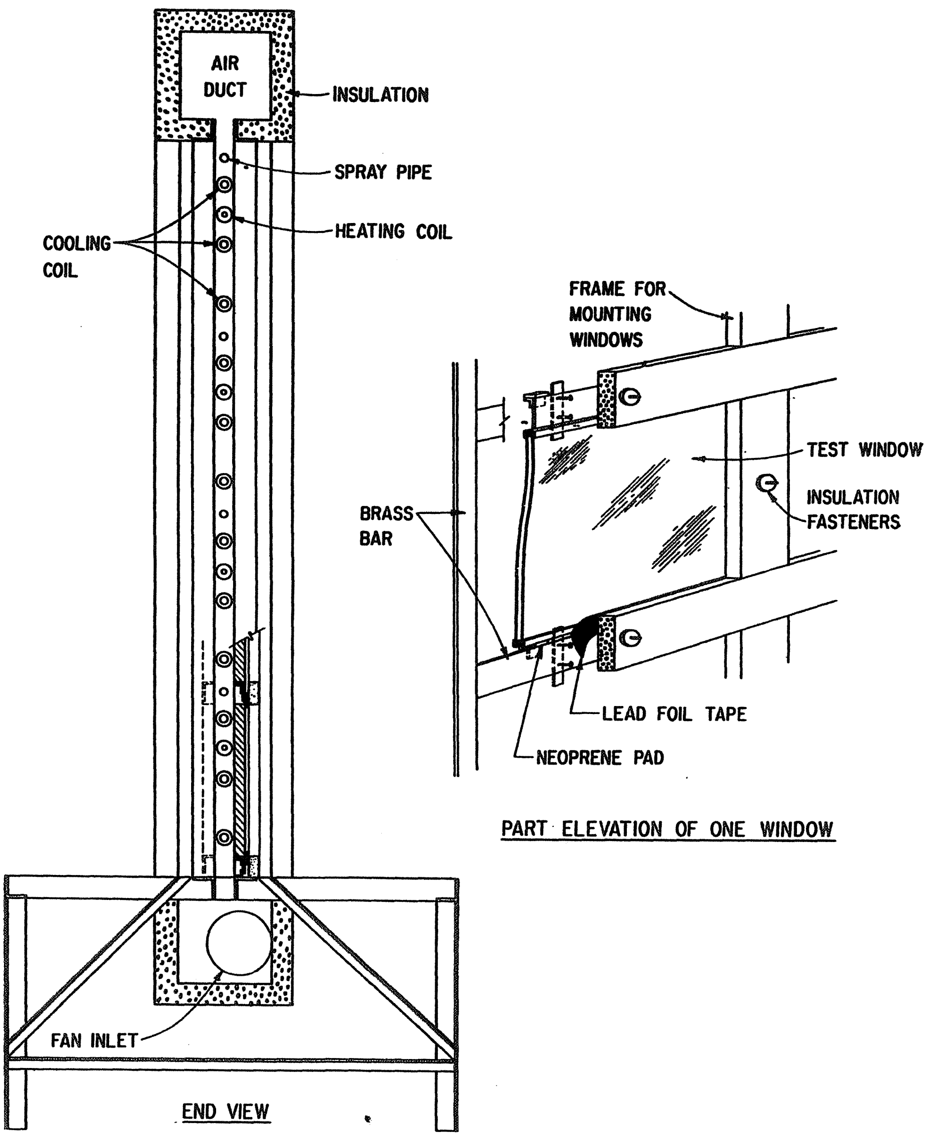

FIGURE 3
Weather simulating device for window tests

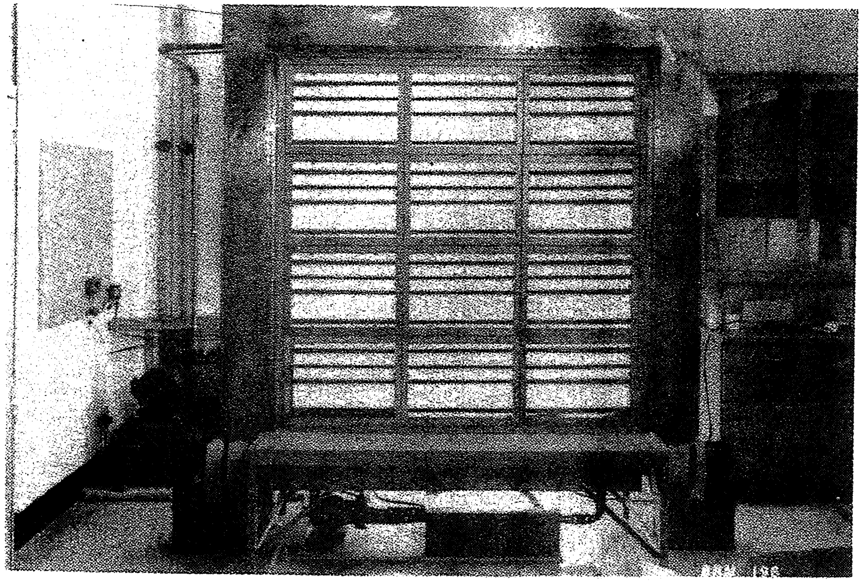

FIGURE 4
Front view of weather simulating device

cycle time being 4 hr. Units are removed every two weeks (80 cycles) and are stored in the laboratory for two weeks before reinstallation in the laboratory weathering apparatus. Prior to reinstallation dew point and vacuum chamber deflection measurements are made. At present CMHC requires that eleven of twelve units from each set have dew points of less than 30°F after 320 cycles.

Laboratory weathering tests on units involved in the early phase of the program generally were continued until dew point temperatures reached 30°F. In subsequent commercial tests, laboratory weathering tests have been terminated after 320 cycles.

The third stage of the program involves exposure of six specimens outdoors to actual weather conditions. In these measurements the units are mounted in a vertical position on a plywood support facing south, with the edges unprotected as in the laboratory weather apparatus. There is a space of 3/4 in. between the units and the plywood and no stress is induced by the mounting arrangement. This test provides exposure to ultra-violet radiation, which is not included in the laboratory weathering. Stressing of the seal is induced by the temperature fluctuations from normal weather conditions. The units are brought into the laboratory every six months for dew point and vacuum chamber deflection measurements. The results of the outdoor tests are compared with those of laboratory weathering. The outdoor weathering studies are of a long-term nature and are intended to assist in the further development of criteria for the laboratory weathering apparatus as well as to provide information on the performance of the units.

The program to date has been directed towards the devolpment of test procedures and criteria that can be applied to sealed double-glazing units as a whole, rather than to sealants and other components of the units. Studies of the physical and chemical properties of the sealing compounds have been avoided, due to the complex nature of these materials, the range of properties of importance, and the rapidity with which sealant technology has grown. A knowledge of such properties and the extent to which they are retained under service conditions is essential for assessing the potential performance of sealants. In addition, however, it is necessary to have methods of test for the completed product, since the performance of the unit depends on the inter-relation of components and on manufacturing techniques.

Results of Test Program

Table I is a summary of the initial dew point temperatures obtained for the first 33 sets of 18 units tested in the current program. It will be noted that all units had initial dew points less than 30°F.

TABLE I
INITIAL DEW POINTS ON SETS OF 18 UNITS FROM 33 SOURCES

Dew Points °F.	No. of Sources
< -100	2
-100 to -60	13
-60 to -30	10
-30 to 0	5
0 to 30	3

The actual dew point temperatures of the units are higher than those measured for two reasons: the surface temperature of the glass on which the dew is observed is greater than that of the acetone/dry-ice mixture due to the temperature gradient in the glass; and the formation of the dew spot removes moisture from the space. The difference between the measured and actual dew point temperature increases as the dew point of the unit decreases. The error also increases as the size of the unit decreases. This error has not been determined but it is suspected that actual dew point temperatures of about -60°F and lower cannot be detected. Studies of the errors in measuring dew point by the method shown are at present under way.

Knowledge of the true dew point is not essential in the laboratory evaluation of sealed units. The dew point measurements are being used primarily as an index of moisture leakage into the space. For this purpose it is only necessary that the method be standardized in order to provide reproducible results. This involves not only standardizing the apparatus and technique, but also prior conditioning of the units to ensure that the air has come into equilibrium with the desiccant at a constant temperature. The need for the latter can be seen from the moisture isotherms for silica gel given in Fig. 1; with 15 per cent desiccant moisture content the dew point is about 27°F at 70°F and only 7°F at 50°F desiccant temperature.

Table II gives the results of the initial vacuum chamber tests on the first 33 sets of 18 units from 31 sources which were tested in the current program. Most noteworthy is the large number of vacuum chamber failures, even though it can be assumed that special care was taken in constructing the units for test. Failures amounted to over 15 per cent of all specimens submitted. In subsequent tests on nearly 700 units about 12 per cent have failed the qualifying vacuum test.

There does not appear to be any correlation between the number of vacuum chamber failures before eventual qualification for laboratory weathering tests and the performance of units under laboratory weathering. Only relatively large leaks are detected in the vacuum chamber deflection test. Many units which fail on laboratory weathering give no indication of leakage in the vacuum chamber.

Table III gives the results to date of the laboratory and field weathering tests

Table II

SEAL LEAKAGE TESTS ON SETS OF 18 UNITS FROM 33 SOURCES

No. of Leaks	No. of Sources
0	18
1	5
2	1
4	3
5	1
10	1
12	1
13	1
15	1
18	1

Total No. of Units 596.
Total No. of Leaks 92-15.4 per cent.
Units from 23 sources passed initial tests on first submission.
Units from 10 sources failed initial tests on first submission.
New units from 9 sources subsequently passed initial tests.
Of 32 sets passing initial tests, 17 have failed to date on laboratory weathering.

on the first 30 sets of units that passed the initial dew point and vacuum chamber deflection tests. So far 17 sets have had more than one failure on dew point temperature in the laboratory weathering apparatus at 320 cycles or less, and tests on these have been discontinued due to lack of space on the apparatus. Tests are continuing on the remainder plus additional sets which have subsequently qualified for laboratory weathering. Only ten of the original 30 sets have had no failures at fewer than 320 cycles.

In the initial phase of the program it had been planned to complete laboratory weathering tests on 12 units of each set, regardless of the number of failures. Pressure for space on the apparatus, however, has increased to the point where tests are now being terminated when two units have failed, that is dew points have exceeded 30°F in fewer than 320 cycles. Because of this and because only a limited number of units have been tested of those that have not failed to date, the table does not give a good statistical picture of the distribution of failures. There is a rough correspondence between failures in laboratory weathering and failures in the field exposure with one notable exception, set DD. In this case it is assumed that the sealant is sensitive to ultra-violet radiation.

In many units exposed to laboratory weathering, rapid dew point temperature rise and failure have occurred without any indication of leakage in the vacuum chamber deflection test. When a leak has been indicated by the vacuum chamber test, failure on dew point rise has occurred on relatively few additional weathering cycles, except in two instances; in both cases the units passed subsequent vacuum chamber tests. Of the eight sets which have shown no failures to date, measurable dew point rises have occurred in all but one set.

Table III

LABORATORY AND OUTDOOR WEATHERING

Set No.	No. of Failures on Laboratory Weathering — No. of Cycles: 0	80	160	240	320	400	480	560	640	720	800	880	No. of Failures at 1 Year Outdoor Exposure
I	12												6
U	12												6
H		11	1										6
FF	3		4	1									6
R			3		3								2
Z		2	2	2	1				1				2
G			2	3		1	1						0
W	2	1		3					1			1	6
X			3	1					2				6
M		2	2		1	1							1
K			1	2	1		1						0
Q			2	1			2				1		2
AA			1		3	1							0
J		1			1	2		3					0
S	1	1		1									0
BB	1		1						1				0
O		1			1			1					1
P	1									4			0
L					1	1						2	0
T											1	1	0
GG								1					1
DD	TWO OF EACH HAVE WITHSTOOD 1040 CYCLES AND TWO 480 CYCLES WITHOUT FAILURE												6
F													1
E													0
N													0
Y													0
D													0
EE													0
V													0

The amount of moisture transfer required to raise the dew point temperature of the air space to 30°F depends on the amount of desiccant and its initial moisture content. For test specimens with no desiccant, the amount of moisture required to raise the actual dew point from -60°F to 30°F, is only about 0.15 grains. For the units containing desiccant throughout the entire length of the spacer the amount of moisture transfer required may be from 300 to 1000 times as much. Thus a relatively large quantity of water is required to produce 30°F dew point in specimens containing desiccant. The coefficient of water vapour permeability of the sealant would have to be many times the acceptable maximum in order to transfer this amount of water by diffusion alone in the period required for 320 cycles (four weeks in the apparatus and four weeks in the laboratory). Failures in the laboratory weathering apparatus in this number of cycles are thus thought to be mainly due to water transfer as a result of pumping action, or capillary flow, through cracks or openings which exist in the units as received, or which develop as a result of stressing under the cycling conditions. In some instances these openings may occur only during one part of the cycle.

To determine the extent of moisture transfer by diffusion in a reasonable length of time requires exposure to higher average vapour pressure differences than are provided by the laboratory weathering apparatus. For this purpose exposing the entire specimen to high humidity, or liquid water, and elevated temperature would have merit. Temperature cycling at the same time would encourage water transfer through any small leaks in the seals by pumping action. Consideration is being given to the use of an apparatus providing such conditions as a further qualifying test preliminary to exposure in the laboratory weathering apparatus. The time required for comparative tests in this, or the laboratory weathering apparatus, could be reduced by requiring a low initial dew point temperature, for example, not greater than -60°F, and by limiting the dew point rise to say 0°F. In comparing the performance of various sealing systems in product development there might be some merit in using specimens containing only enough desiccant to produce a low initial dew point, or to omit the desiccant and dry the air space by other means in order to obtain a measure of seal leakage within a short time.

Conclusion

The results of the laboratory program on evaluation of sealed double-glazing units emphasize the extreme difficulty of providing and maintaining an effective sealing system. Many units are imperfect as manufactured; others will probably develop defects under stresses imposed in service. Calculations indicate that units with imperfect seals, which will fail within the expected life of the building, may perform satisfactorily in the field for several years, particularly if desiccant is employed to dry the air space.

Field experience with units from the majority of present sources does not exceed 4 or 5 years. Satisfactory performance over this brief period cannot be taken as an indication of acceptable long-term service. Suitable standard laboratory methods are required by both consumer and producer for evaluating sealing systems. These should include both tests on components of the seal, particularly organic sealants where used, and on the complete unit. Emphasis in the DBR program to date has been on the development of a laboratory weathering procedure to determine the ability of units to maintain a seal under the types of stresses induced by natural weather forces, particularly temperature fluctuations and water. The apparatus has been very successful in identifying units with mechanically weak seals. The testing time required to indicate the resistance to water vapour diffusion of sealing systems is excessive, however, due to the low rates of moisture transfer by this mechanism. Furthermore, the number of specimens that can be accommodated in the apparatus is limited. An additional procedure which would accelerate moisture transfer by diffusion and also identify units having leaks too small to appear in the vacuum chamber deflection test would be advantageous as a further qualifying test prior to exposure on the laboratory weathering apparatus. Test methods are also required to determine the extent to which sealing materials are likely to retain necessary physical and chemical properties under long-term service.

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