REPRINT 145

Laboratory testing of sealed glazing units

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NORWEGIAN BUILDING RESEARCH INSTITUTE

OSLO 1967

Norges byggforskningsinstitutt

Extrait du Bulletin Rilem n° 35 — Juin 1967

MÉTHODES ET APPAREILS DE LABORATOIRES

LABORATORIES METHODS AND DEVICES

Laboratory testing of sealed glazing units

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Introduction

"Sealed glazing units" is a common term for various types of factory-made glass products. These units consist of two or more panes of glass, kept at a certain distance by a spacer at the edges, and sealed along the edges to provide a hermetical seal. The space between the panes is filled with cleaned and dehydrated air or gas. The most common types have two sheets of glass and a 12 mm wide air space, and are sealed at normal atmospheric pressure.

The existing types of sealed glazing units can be divided into three main groups, as shown on figure 1.

Group I covers all-glass constructions with fused glass edges. These types have so far only been made as double-glazing units. The manufacture is carried out by keeping two sheets of glass at a certain distance, while the edges are heated, melted and welded together. A small hole is left in one of the corners, which is used to blow in filtered, cleaned and dried air before the units are finally sealed off. The fusion of the glass edges results in a completely rigid construction. This is the reason why these types of units have so far only been made with small air spaces, from 5 to 7 mm. With wider air spaces, there is an increased risk of breakage due to the deflection of the glass by changing atmospheric pressure and temperature.

Group II covers units with a soldered metal spacer and a direct glass-to-metal seal. The edges of the glass panes are first metallized with molten copper metal and afterwards coated with tin. A thin strip of a lead alloy is soldered to the tinned glass edges. A few small holes are made in the spacer strip, and the air between the panes replaced by filtered and dried air before the holes are soldered and the units sealed off. The glass-to-metal seal itself is quite rigid, but on account of the thin lead spacer strip, the entire construction must be regarded as semi-rigid. The units are usually made as double- and triple-glazing units, but can also be made with a higher number of layers of glass. Present air spaces are from 6 to 15 mm.

Group III covers units with a spacer strip glued to the glass. The actual constructions utilize spacers of different materials with quite different cross-sections and corner solutions. In most cases metal channel spacers are used, completely or partly filled with a dehydrating material, e.g. silicagel. Frequently a U-shaped external channel is used to protect the edges of the glass and assist in keeping the units

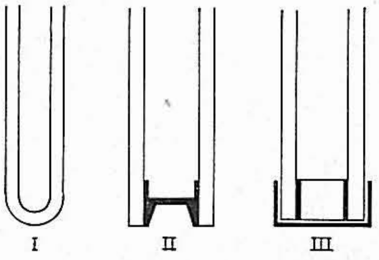

FIG. 1. — **The three main groups of sealed glazing unit constructions.**

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together. Dependent on the materials used, soft, semi-rigid and rigid constructions are obtained. Most types can be supplied as double- and triple-glazing units, as well as with a higher number of layers of glass. Present air spaces are from 4 to 19 mm.

A more detailed description of some types of units is given in one of the Architectural Data Sheets [1] of the Norwegian Building Research Institute. The sealed glazing units came into the Norwegian marked in 1950 as an alternative to the conventional double windows. The most important difference between these products lies in the condition of the air space. In double windows, the air space has to be ventilated on the outside to prevent condensation between the panes on the inner surface of the outer layer of glass. In sealed glazing units this problem is solved by means of the hermetical edge seal and dehydration of the air space.

Condensation between the panes of sealed glazing units will not occur in practice as long as the edge seal is sufficiently tight and the initial dehydration is adequate. If the seal should deteriorate, however, the moisture content of the air space will gradually increase, and condensation may occur under certain temperature conditions. The transport of humidity into the units can be by air flow as well as by diffusion. Other processes, such as separation of water from the adhesives, may also contribute to increase the humidity level. With greater seal, leaks, dust particles, etc. may follow the air currents.

Condensation between the panes can in itself be sufficiently troublesome. Far more important, however, is the subsequent soiling of the glass surfaces by alkaline constituents, which are brought to the glass by a leaching process and deposited there. This is called "scumming". A sealed glazing unit must be regarded as defective as soon as condensation has occurred between the panes. Strict requirements should be made on the tightness and durability of the edge seal.

Investigation of the performance of sealed glazing units

The first laboratory tests at the Norwegian Building Research Institute were carried out as early as 1959, and the results published in 1962 [2]. Similar investigations have been carried out independently in Australia [3], Canada [4, 5] and U.S.A.[6].

The first field studies of the Norwegian Building Research Institute were also undertaken in 1959 in the Trondheim area. Later they were followed by a comprehensive study in East Norway [7] and a far more expensive study in West Norway [8, 9].

These investigations have clearly shown that it is very difficult to manufacture units with an effective and durable edge-seal. In the case of some types the results are good and the expected span of life is fully acceptable, in the case of other types the results are surprisingly bad. The less successful types have now fortunately disappeared from the market. We cannot be sure, however, that second-rate products will not appear again, unless reliable accelerated test methods are available. The demand for accelerated testing was the occasion for the first laboratory tests at the Norwegian Building Research Institute [2], as well as all the laboratory tests that have been carried out in recent years, largely as sponsored work for different private companies. The general experience derived from these tests will now be considered

Stresses on the edge seal

The actual strains on the edge seal of sealed glazing units were thoroughly examined before the tests were started. It was thought necessary to subject the edge seal to the same stresses as in practice, but in a considerably accelerated degree. Shock effects which did not normally occur in practice, were as far as possible avoided.

The stresses on a unit can of course differ considerably from one case to another, but the following types of strains are at least actual :

a) *Transportation stresses* which the units may be subjected to on their way from the factory to the building site. These strains can be of a mechanical nature, such as blows, shocks and vibrations. They may also be caused by variations in the atmospheric pressure during transportation at different heights above sea level.

b) *Assembling stresses* at the building site will also mainly be of a mechanical nature, and will vary with the care taken during the installation of the units. There are several other possibilities, namely wrong dimensioning of window sashes and frames, warping, inadequate rebate design, wrong blocking of units, chemical reactions between putties or sealing agents and the edge seal, etc.

c) *Variations in the atmospheric pressure* will strain the units in the same way as variations in altitude. A pressure difference will result in an air flow through the small leaks which may exist in the edge seal. A change in atmospheric pressure will also result in a deflection of the glass panes toward or away from each other, and subject the edge seal to a twisting motion.

The annual fluctuations in the atmospheric pressure in Norway may amount to 120 millibars and the variations during one day to 30 to 40 millibars. These variations act partly as a super-pressure and partly as an under-pressure ; they are also partly equalized by the deflections of the glass panes and the corresponding changes in the volume of the air space. These factors will greatly reduce the significance of the variations in the atmospheric pressure. Calculations have shown that the maximum deflection at the centre of the glass panes will be less than ± 10 % of the air space width ; in the case of 12 mm air space, less than ± 1 mm.

d) *Changing temperatures* will influence the edge seal in two different ways. In the first place, heavy sheering stresses may develop in the edge seal, dependent on the coefficients of expansion of the materials. These stresses will be greatest at the corners of the unit, and proportional to the length of the edge of the unit. Further, a change in the average temperature of the air space will strain the edge seal in the same way as variations in the atmospheric pressure.

Sealed glazing units will in practice be subjected to considerable temperature changes. The highest temperature will occur when a dark wall cladding faces the sun. In such a case the temperature of the rising airflow may amount to at least + 70 °C. The lowest winter temperature in Norway is about — 40 °C. Fluctuations between these extremes will be spread over a considerable length of time, but it is possible that the variations between night and day may be as high as 50 °C.

e) *Wind stresses* may easily reach a high level, especially in exposed locations. The standard formula for wind pressure is :

$$p = \frac{1}{16}\left(v \pm \frac{v}{2}\right)^2$$

where p is the wind pressure in mm water column, v the average wind velocity in m/s over a 10 minute period and $\pm \frac{v}{2}$ represents the variations, the wind gusts, within this period. Many localities along the Norwegian coast will have storm periods every year, where the super-pressure during the wind gusts may be as high as 100-150 mm water column, in some cases considerably higher. Even in more sheltered locations, the stresses on multi-story buildings may be very severe.

The wind pressure acts mainly on one side of a sealed glazing unit, and will subject the glass to large deflections. The pane size and glass thickness will, of course, have a marked influence. With the glass thicknesses normally used, the central deflection of the panes may easily amount to 5 mm.

f) *Sunlight, especially ultra-violet light,* may have a serious effect on units where the tightness of the edge seal depends upon a glued or cemented bond. A number of organic sealants have proved to lose adhesion to glass if the interface is subjected to solar radiation. In a number of glued constructions, however the glued faces are protected against direct radiation by external metal profiles. On installed units, the rebate, beads, sealants, etc. provide further protection. Under normal conditions only multi-reflected radiation will reach the glued interfaces.

g) *Water* has been found to lead to a rapid failure of the edge seal, especially in some types of glued constructions. The units in question were, however, improperly installed, and were more or less standing in water. In recent years a number of investigations relating to the installation of sealed glazing units have been carried out [10, 11, 12, 13, 14, 15]. With the present installation recommendations [16] it should be possible to avoid earlier mistakes.

h) *Mechanical stresses caused by vibration* will occur, particularly where the units are mounted in doors or opening windows, in buildings with heavy machinery and in structures exposed to heavy vibrations from traffic and sound waves. At first, little was known about the influence of these strains. Subsequent field studies have shown that this type of strain may be of vital importance in special cases.

Of the types of stresses dealt with here, transportation and installation strains must be considered as more or less arbitrary. Transportation strains can easily be reduced by suitable measures, and with the present installation recommendations [16], the assemblage strains can be virtually eliminated. The real climatic strains must be said to be variations in the atmospheric pressure, changing temperatures, wind and sunlight. Water and vibrations can certainly be of importance in special cases, but ought to be excluded from normal test methods.

On the basis of earlier considerations it was decided to build an apparatus where installed units could be subjected to temperature changes and pulsating wind pressure. It was found that variations in the atmospheric pressure could be omitted, as the stresses derived from the two other factors would then be considerably stronger. On the other hand it was thought desirable to include sunlight. This factor had, however, for practical reasons, to be dropped. A unit size of 120 × 170 cm with about 12 mm air space, and a glass thickness of about 4 mm was estimated to correspond most correctly to actual conditions.

Apparatus for dew point measurements

It is, as already mentioned, important that the amount of humidity in the air space is so small that condensation between the panes will not occur in practice. Dew point measurements are then of great interest. The dew point itself is by definition the temperature at which the pressure of saturated water vapour is equal to the actual vapour pressure in the air, and should not be confused with the outside air temperature at which a unit would possibly exhibit visible condensation between the panes.

The dew point of sealed glazing units can be checked by a local cooling of a part of the glass surface, until condensation as dew or frost occurs on the surface facing the air space in the unit. Figure 2 shows a cross-section of the type of cooler developed at the NBRI Laboratory in Trondheim. This cooler is made of brass and the cooling surface is polished and nickle- and chrome-plated. When dew point measurements are taken, the cooler is filled with a mixture of dry ice and alcohol, having a temperature of — 75 °C. Originally the dew point measuring method was based on thermocouples glued to the outside glass surfaces. During the measurements the cooler was then placed against the glass, so that a thermocouple was located in a groove in the cooler without being in contact with it. Proper thermal contact was obtained by cleaning the cooling surface and the glass with alcohol. The glass was allowed to cool and the temperature registered at the moment when condensation was observed. All dew point temperatures were then measured on the outside surface at the moment when condensation took place on the inside.

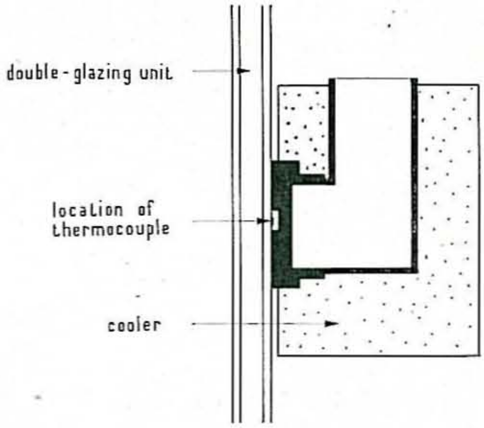

FIG. 2. — **Dew point measurement on double-glazing unit.**

This method has later on been further developed [17]. First the externally measured dew point temperature was calibrated as a function of the dew formation time. In this way the thermocouple and the appurtenant measuring equipment could be omitted. Finally, curves were drawn showing the relationship between the dew formation time and the real dew point at the air between the panes. These curves are

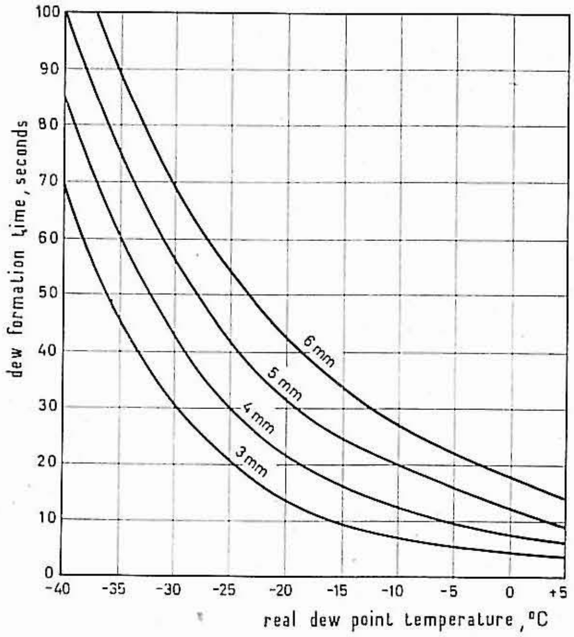

FIG. 3. — **Dew formation time versus real dew point temperature, NBRI measuring method. Unit temperature + 20 °C, glass thickness 3 to 6 mm.**

shown on figure 3. The highest acceptable dew point has, with a certain degree of safety, been fixed at — 5 °C. This is called the critical limit.

Apparatus for climatic stresses

Figure 4 shows the NBRI apparatus for climatic strains on sealed glazing units in its present form, after improvement. In the beginning the apparatus had a somewhat different appearance, but has in principle been the same all the time. The system consists of three frames made of teak wood. In each frame four casements can be attached, each bearing a sealed glazing unit. When the installation is completed, closed chambers are formed, in which air with adjustable pressure and adjustable temperature can be circulated. In other words, the air in the closed chambers represents the outdoor climate. The complete apparatus is located in the laboratory, which represents the indoor climate with a temperature of about + 20 °C.

The apparatus can be adjusted in two ways. One method is to let a high pressure fan supply the air to the chambers. A pulsating damper regulates the air supply, so that the pressure within the chambers pulsates, like wind gusts. This pulsation corresponds quite well to the pressure variations according to

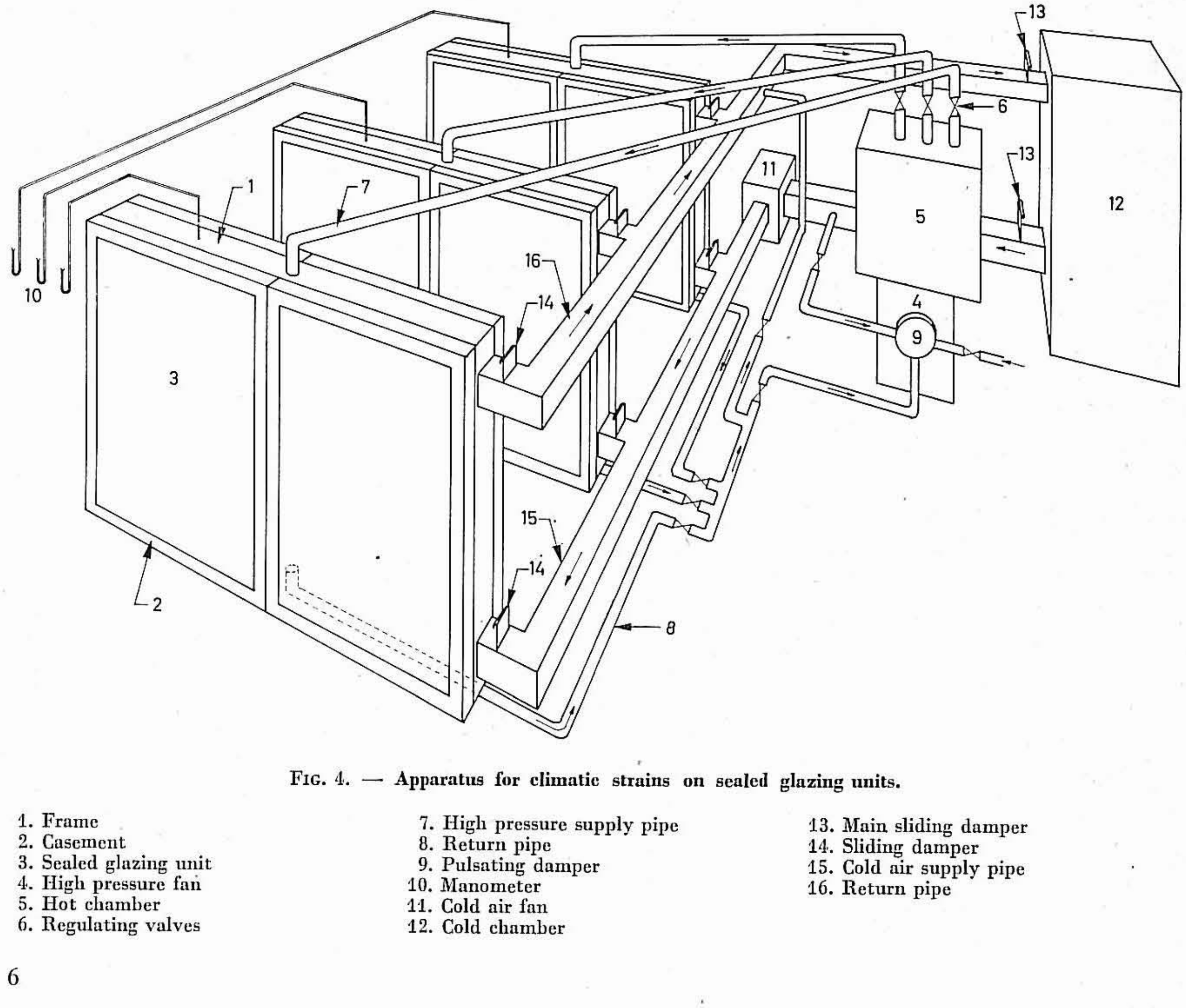

FIG. 4. — **Apparatus for climatic strains on sealed glazing units.**

1. Frame
2. Casement
3. Sealed glazing unit
4. High pressure fan
5. Hot chamber
6. Regulating valves
7. High pressure supply pipe
8. Return pipe
9. Pulsating damper
10. Manometer
11. Cold air fan
12. Cold chamber
13. Main sliding damper
14. Sliding damper
15. Cold air supply pipe
16. Return pipe

the wind pressure formula $p = \frac{1}{16}\left(v \pm \frac{v}{2}\right)^2$. The pulsating damper had in the beginning a frequency of 6 periods per minute, but was changed to 5 periods per minute after the first series of tests. The maximum super-pressure within the chambers during the wind gusts can be varied between 10 and 100 mm water column, corresponding to wind force Beaufort No. 5 to 11. The temperature inside the chambers, measured centrally in front of the units, can be varied between + 10 and + 50 °C. The lowest temperatures are reached by adding in cold air from the cold chamber.

The second method is to let a low pressure fan blow cold air directly from the cold chamber through a larger set of pipes. In this way the temperature inside the chambers can be lowered to about — 10 °C. The super-pressure, however, is insignificant, and pulsation is not possible. By changing from a hot to a cold period, the units can be subjected to temperature changes.

Test procedures

For the first series of tests the installation of the units in the apparatus was carried out by experienced craftsmen. The installation method employed proved, however, quite soon to be inadequate for Norwegian climatic conditions. In the further tests, a better method was used in which the lateral clearances were secured by spacers, as shown on figure 5, and the work carried out by the laboratory staff.

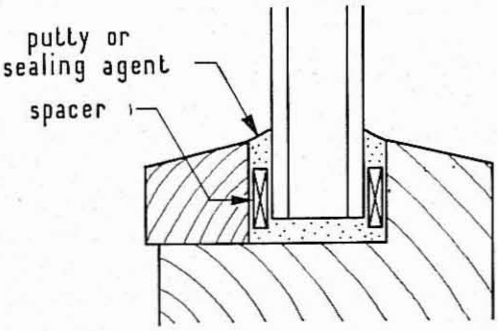

FIG. 5. — **Sealed double-glazing unit installed with spacers.**

In the first laboratory tests the wind stresses were started at a moderate level, and gradually increased step by step. The details of this programme will appear from NBRI Report No. 33. In all later tests, from 1961 and onwards, the stresses have been in accordance with a somewhat revised test programme, based on experience from the first tests and the later meteorological data [18]. In carrying out this programme, an attempt was made to include 20-year wind stresses in comparatively exposed places. The wind pressure and air temperature have always followed a day-cycle consisting of 4 hours cooling at a low and constant air pressure to an outside air temperature of about — 10 °C, followed by a 20 hour period with 5 wind gusts per minute under simultaneous heating to a prescribed temperature level. The actual temperatures, the maximum wind pressures during the wind gusts and the number of day-cycles at each period of strain are indicated in Table I.

This 45-day programme has been repeated once, making a total effective operation time of 90 day-cycles. Slight variations in the operation cycles have of course occurred, but have been insignificant both in magnitude and duration.

The units have always been inspected regularly for visible damage during the operation of the tests. Dew point measurements have been taken at the beginning and at the end of each period of stress, as well as with regular intervals during each period, usually twice a week. Finally the units have been taken out for inspection. Usually they have also been taken apart and the edge seal examined in detail.

Results

A major part of the tests have, as already mentioned, been carried out as sponsored work for different private companies. The results are in such cases the property of the sponsor, and cannot be published by the NBRI without the consent of the sponsor. It is, therefore, only the general results that will be given here, without giving the names of the products.

The results can be divided into visible damage in the units and changes in the dew point.

The visible damage comprises cracks in the glass, cracks in the metal seal and deflection of the metal seal.

Cracks in the glass have occurred in different types of unit, in Group I as well as in Groups II and III (see figure 1). It appears, however, that the cracks have always started at the edge of a spacer. The reason is that the bead has been forced back so hard that the unit and spacer have got jammed. Similar cracks have also occurred in practice. Mounting with spacers must always be carried out with some care.

TABLE I

Period of strain	I	II	III	IV	V
Day-cycle number	1-10	11-30	31-34	35-44	45
Maximum pressure during the wind gusts, mm water column.	40	25	70	15	100
Corresponding to wind force Beaufort No.	8	7	10	5	11
Air temperature °C	25	35	15	50	15

Some types of all-glass units, in Group I, must either be installed with special types of spacers or entirely without such.

Cracks in the metal seal have only occurred in units in Group II. They have been localized to the central part of the long sides of the units, in some cases also to the short sides. In the laboratory tests the cracks have occurred at a comparatively late stage, after the units have been subjected to prolonged strains. In practice, however, they have so far only occurred in units installed in doors with heavy traffic frequency or close to such doors. The cracks have always had the appearance of typical fatigue breaks at the weakest and most heavily strained part of the edge seal, and are undoubtedly due to pulsation stresses.

Deflection of the metal seal is characteristic of certain periods of production in some types of unit in Group III. Deflections up to 2 cm have been measured in practice, in the laboratory as much as 7 cm.

The changes in dew point during the laboratory tests have differed greatly for different types of unit. Some typical cases are shown on figure 6.

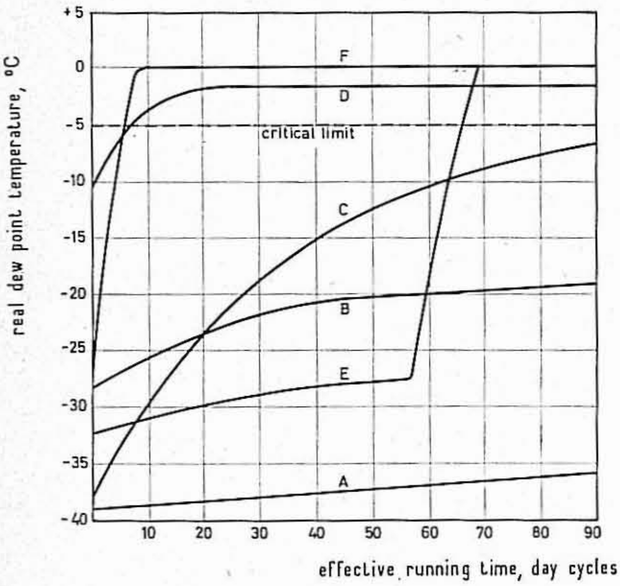

FIG. 6. — **Typical examples of measured dew-point temperatures.**

Curve A is typical of a good unit where the dew point is not influenced significantly by the stresses. In curve B there is first a certain increase, which may be due to changes in temperature, separation of water from the adhesives during curing, etc. Also units with this type of dew-point curve have, however, to be considered as good. In curve C, the situation is quite different. Here the dew point rises so rapidly towards the critical limit that the units have undoubtedly got considerable leaks. Curve D must be considered as showing a real production failure, as the dew point has from the outset been much too high. Something between curves B and D can be judged somewhat different, according to where the curves start and end.

Curves A-D represent units without visible damage. In the case of units with visible cracks in the metal seal, the dew point will follow curve E and suddenly rise above the critical limit when the cracks have occurred. For units with deflection of the metal seal, there will be a corresponding rapid increase, as for instance curve F.

Practical experience [8, 9] has confirmed that the dew point for good units will rise slowly in course of time like curves A and B. For bad units, the dew point can easily rise above the critical limit and result in condensation. Units with a much too high nicipient dew point have also occurred.

Evaluation of the test method

There is in many ways a surprisingly good correlation between the results of the laboratory tests and the field studies. The types of damage that have occurred are exactly the same, and in the case of units without visible damage, the dew points have developped in a completely parallel way. The method undoubtedly reveals something about the ability of the edge seal to resist climatic strains. It has also shown the enormous importance of rapid pulsation stresses, such for instance as wind or vibrations.

It is a different matter whether the strains are on a right level or not. In the units in Group II, cracks in the metal seal, as mentioned before, developed in the later part of the laboratory tests. In practice, such cracks have so far only been found in units installed in doors or adjacent to doors, while the great mass of units have shown good performance. This indicates that the wind strains may have been too severe. The duration of the wind strains is, however, based on meteorological data and is undoubtedly realistic in accordance with the conditions. The remaining factor is then the 5 wind gusts per minute, which is probably too high a figure. Recent wind measurements also indicate that 5 strong wind gusts per minute is too high a figure. The test programme has therefore now been up for revision. The plan is to maintain the number of temperature changes and reduce the number of wind gusts to about the half. This will be possible by running two temperature changes per day cycle. Total testing time will then be about 55 days.

Furthermore, certain special tests may be necessary as a supplement to the duration test. By fixing a reasonable requirement for the starting dew point, e.g. — 25° C, expensive and time-consuming tests with units having a much too low starting dew point, can be avoided. See, for instance, curve D, figure 6. Control in a vacuum chamber can also help in eliminating units which are not sufficiently tight from the beginning. Finally an additional test to check the resistance to sunlight, may be appropriate.

REFERENCES

[1] *Sealed glazing units, types and properties.* Architectural Data Sheet NBI (31). 103, Norwegian Building Research Institute, April 1965 (in Norwegian).

[2] GJELSVIK Tore. — *Tests with factory-sealed double-glazed window units.* Norwegian Building Research Institute, Report No. 33, Oslo, 1962 (in English).

[3] BALLANTYNE E. R., BROWN N. G. — *Scumming of factory-sealed double-glazed window units.* Australian Building Research Congress 1961 (in English).

[4] WILSON A. G., SOLVASON K. R., NOWAK E. S. — *Evaluation of factory sealed double-glazed window units.* ASTM Special Technical Publication No. 251, 1959 (in English).

[5] WILSON A. G., SOLVASON K. R. — *Performance of sealed double-glazing units.* Research Paper No. 168 of the Division of Building Research, National Research Council of Canada, Ottawa, 1962 (in English).

[6] MAZZONI R. J., KING L. K. — *Performance of double-glazed units in accelerated and service tests.* Material Research & Standards, Vol. 5 (1965), No. 10, pp. 517-524 (in English).

[7] BASTIANSEN Alf. — *Sealed glazing units in Norwegian climate.* Bygg, No. 2, 1961, pp. 29-36. Norwegian Building Research Institute, Reprint No. 53, Oslo, 1961 (in Norwegian).

[8] GJELSVIK Tore. — *Performance of sealed double-glazing units in severe Norwegian climate.* The West Coast Field Study 1963. Norwegian Building Research Institute, Report No. 44, Oslo, 1965 (in English).

[9] GJELSVIK Tore. — *Durability of sealed glazing units.* Byggmesteren, No. 24, 1965, pp. 19-20, 23, 27-28, 31-32 and 34-36. Norwegian Building Research Institute, Reprint No. 115, Oslo, 1965 (in English).

[10] GJELSVIK Tore. — *An investigation of glazing sealers and installation methods for factory-sealed double-glazed units.* Norwegian Building Research Institute, Report No. 32, Oslo, 1961 (in English).

[11] GJELSVIK Tore. — *Supplementary investigations concerning glazing sealants and installation methods for factory-sealed double-glazed units.* Norwegian Building Research Institute, Report No. 37, Oslo, 1963 (in English).

[12] GJELSVIK Tore. — *Glazing rebates and beads for sealed glazing units.* Norwegian Building Research Institute, Reprint No. 86 B, Oslo, 1964.

[13] GJELSVIK Tore. — *Why does the oil bleed from the mastic?* Byggmesteren, No. 17, 1964, pp. 41 and 44-48. Norwegian Building Research Institute, Reprint No. 97, Oslo, 1964 (in Norwegian).

[14] GJELSVIK Tore. — *Pretreatment of wood before application of putties and sealing compounds.* Byggmesteren, No. 15, 1965. Norwegian Building Research Institute. Reprint No. 108, Oslo, 1965 (in Norwegian).

[15] GJELSVIK Tore. — *Edge effects and other thermal properties of windows with sealed glazing units.* Byggmesteren, No. 9, 1966, pp. 17, 19, 21-22, 25, 27, 29 and 31. Norwegian Building Research Institute, Reprint No. 129, Oslo, 1966 (in Norwegian).

[16] *Sealed glazing-units. Installation in frame or sash of wood or directly into wooden framework.* Architectural Data Sheet NBI (31). 202.2. Norwegian Building Research Institute, April 1965 (in Norwegian).

[17] GJELSVIK Tore. — *Humidity in the dehydrated air space of sealed glazing units.* In the press as report from the Norwegian Building Research Institute (in English).

[18] JOHANNESSEN Thor Werner. — *Monthly frequencies of concurrent wind forces and wind directions in Norway.* Norwegian Meteorological Institute, Oslo, 1960.

ÉDITÉ PAR LA S.D.T.B.T.P. 9, RUE LA PÉROUSE. — PARIS-XVIe

6029-7-1967. IMPRIMERIE FIRMIN-DIDOT. - PARIS - MESNIL - IVRY - Dépôt légal : 3e trimestre 1967. *(Le Gérant : R. L'HERMITE.)*

Reprint from „RILEM BULLETIN" nr. 35, 1967
Omslaget trykt i J. Petlitz Boktrykkeri (Rolf Rannem), Oslo