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PROJECT REPORT 9

Norwegian Building Research Institute

Tore Gjelsvik,
Kristin Breder, Jarle R. Herje and
Einar M. Paulsen

Four Papers on Durability of Building Materials and Components

Oslo/Trondheim 1986

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Preface

The Trondheim Division of the Norwegian Building Research Institute has a specialized and trained staff. They act as advisers and consultants for manufacturers as well as users of building materials and components. A special feature of the division is the development of specialized test methods and laboratory test equipment. Another important point is the collection of practical experience.

The four papers presented in the present report represent four different aspects of the durability complex.

- The first paper is giving results of accelerated testing of PVC roofing materials in the NBI special apparatus Mark 1 and comparing with results from natural exposure
- The second is correspondingly giving results from testing of wooden windows with organic coatings in apparatus Mark 2, compared with natural exposure
- The third is dealing with accelerated testing of glass-fiber reinforced polyester in apparatus Mark 1 compared with accelerated natural exposure
- Finally the fourth is presenting results from long time practical experience with sealed glazing units, up to 32 years old.

Three of the papers were first presented at the "Third International Conference on the Durability of Materials and Components" in Helsinki 1984, the fourth at "Windows in Building Design and Maintenance" in Göteborg 1984. The combined presentation in this report makes it easier to study the four papers and compare.

The Royal Norwegian Council for Scientific and Industrial Research (NTNF) has contributed to the printing costs.

Oslo/Trondheim, January 1986

Åge Hallquist

Åge Hallquist

Contents

Accelerated and Natural Weathering of Single-layer PVC Roofing Materials

by

Kristin Breder, technical physicist MNIF
Tore Gjelsvik, technical physicist MNIF, MNFS and
Einar M. Paulsen, civil engineer MNIF

Abstract

In 1978, the Norwegian Building Research Institute published a report on laboratory testing of six types of single-layer PVC roofing materials. The studies were made on new materials as well as materials aged for 336 days in the special appartus for accelerated weathering, Mark 1.

The 1978 report showed that the most interesting property was the cold flexibility, determined by folding at low temperatures. For other properties, only minor changes were in most cases recorded after accelerated ageing, while for folding at low temperatures the differences were more significant. This was specially true for one type of material.

In 1982 and 1983, three roofs with two of the previous tested materials could be inspected. The samples taken from these roofs had been exposed to natural weathering for 6-8 years. The cold flexibility of these materials showed interesting correlations with the earlier laboratory tests.

Résumé

En 1978, l'Institut Norvégien du Bâtiment a publié un rapport sur des essais en laboratoire avec six types de toiture PVC feuille simple. Les études étaient effectué avec les matériaux neufs aussi bien que les matériaux vieillis 336 jours en appareil spécial pour étudier la tenue aux intempéries, Type 1.

Le rapport de 1978 indiquait que la propriété plus intéressante était la flexibilité froide, déterminé par le pliage en températures basses. Pour les autres propriétées, seulement les changements mineures étaient en plus les cas observées après vieillissement accelerée, quand pour le pliage en températures basses, les différences étaient plus significantes. C'était paticulierment vrai pour un type de matériaux.

En 1982 et 1983, expérience pratique avec deux des six types de matériaux pouvait finalement être recuilli en toits exposées aux intempéries naturelles pour 6 à 8 années. La flexibilité froide de ces matériaux montraient les corrélations intéressantes avec les essais plus tôtes en laboratoire.

Introduction

Based on initiative from official authorities, builders and consultants, the Trondheim Division of the Norwegian Building Research Institute (NBI) in 1975 started to work out criteria for judging the quality of single-layer PVC roofing materials. The final test programme was dated 14th September 1976, and used for a series of tests with commercially available products.

Five different companies took part in these tests, and supplied a total of six different materials. All products were PVC materials for use as single-layer roofing membranes, but they were compounded and composed in different ways. The following grouping has been found convenient:

Group I Homogeneous membranes (A, B, C and D) made of one or more films

Group II Membranes with reinforcing core materials (E and F)

a) with polyester fabric (increased strength)

b) with glassfibres (dimensional stability).

The testing was carried through in 1976-77, and the final report published in 1978 (1). Selected parts of the results will be presented here together with practical results from later field studies.

Test programme

The following testing was covered by the final test programme:

On fresh material

- tensile strength/elongation at break
- water vapour permeability
- cold flexibility
- weight/dimensions
- splitting force
- puncture resistance.

After accelerated ageing in NBI apparatus, Mark 1

- tensile strength/elongation at break
- cold flexibility
- weight/dimensions
- puncture resistance.

After accelerated ageing in Xenotest apparatus

- tensile strength/elongation at break.

It is necessary to connect a few comments on the different tests:

Accelerated ageing

Two samples of each material measuring 500 mm x 500 mm were mounted in vertical position in the special apparatus for accelerated weathering of building materials and components, Mark 1, Figure 1, at the Norwegian Building Research Institute (2). One of the samples was taken out for testing after 16 weeks, the second after 48 weeks in the apparatus. Test pieces for determination of tensile strength and elongation at break as well as other interesting properties were cut out to the required number and shapes.

Two smaller samples, 45 mm x 150 mm, were mounted in a Xenotest apparatus and run for 1000 and 3000 hours respectively according to DIN 53387. Both samples were used for testing of tensile strength and elongation at break.

Tensile strenght/elongation at break

These properties were tested according to DIN 53455 with some minor modifications. The testing was done on fresh material at 296 K (+23 ^{o}C) as well as on aged material.

Water vapour permeability

Tested to DIN 53122, only on fresh material.

Cold flexibility

Carried out according to DIN 53361, Figure 2, folding at low temperature, on fresh material as well as material aged for 16 and 48 weeks in the NBI apparatus, Mark 1. Agreed test temperature was 243 K (-30 ^{o}C), but additional tests were in some cases made at other temperatures.

Changes in weight and dimensions

Measurements were taken at the start as well as after 16 and 48 weeks of accelerated weathering, and changes in weight and dimensions calculated.

Splitting force

Relevant only for reinforced materials. The test method used was DIN 53357.

Puncture resistance

The test method and equipment used was developed by the Norwegian Building Research Instute (3), Figure 3. The testing was partly done with the membrane material on a soft substrate, partly on the membrane alone. Resistance to puncture was tested with one conical and one shisel shaped test body at temperatures of 296 K (+23 ^{o}C) and 263 K (-10 ^{o}C).

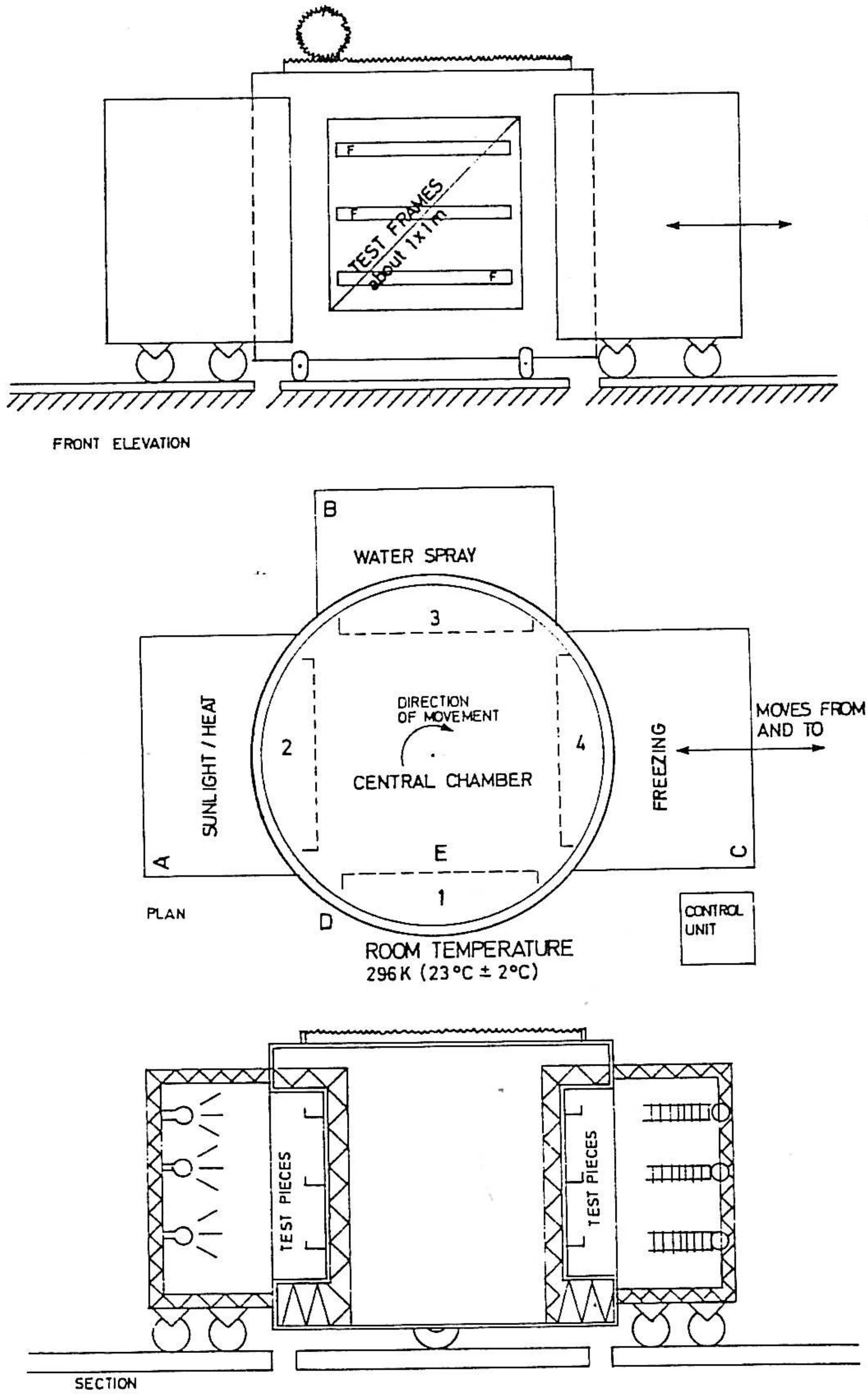

Fig. 1. Apparatus for accelerated weathering of building materials and components in vertical position, Mark 1

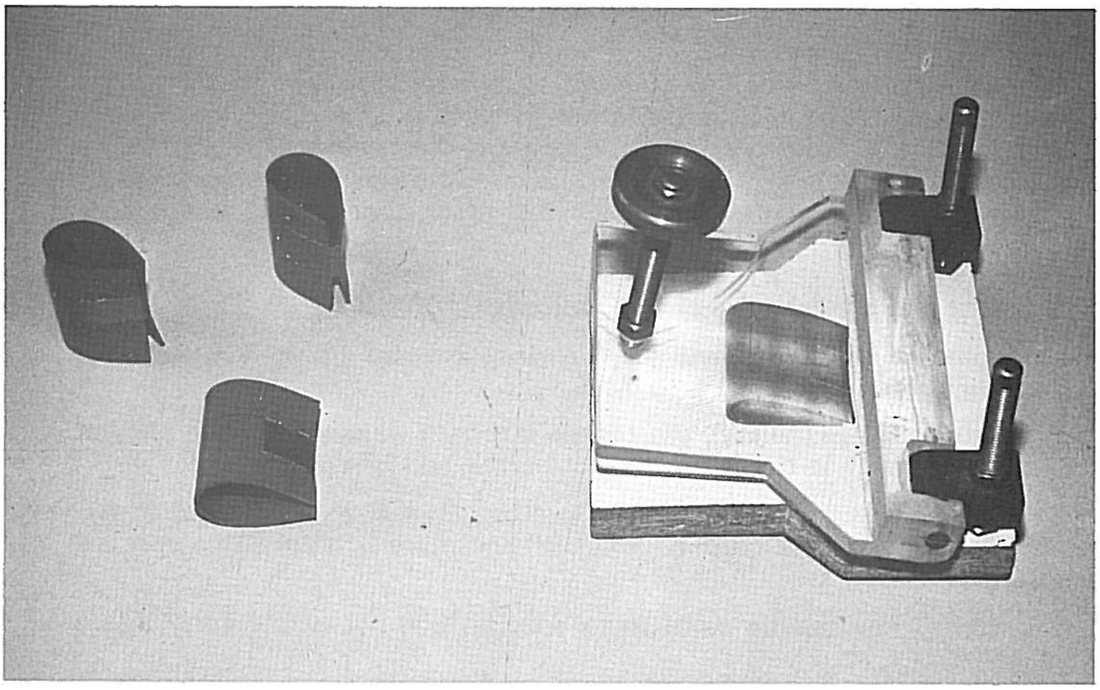

Fig. 2. Folding at low temperature according to DIN 53361

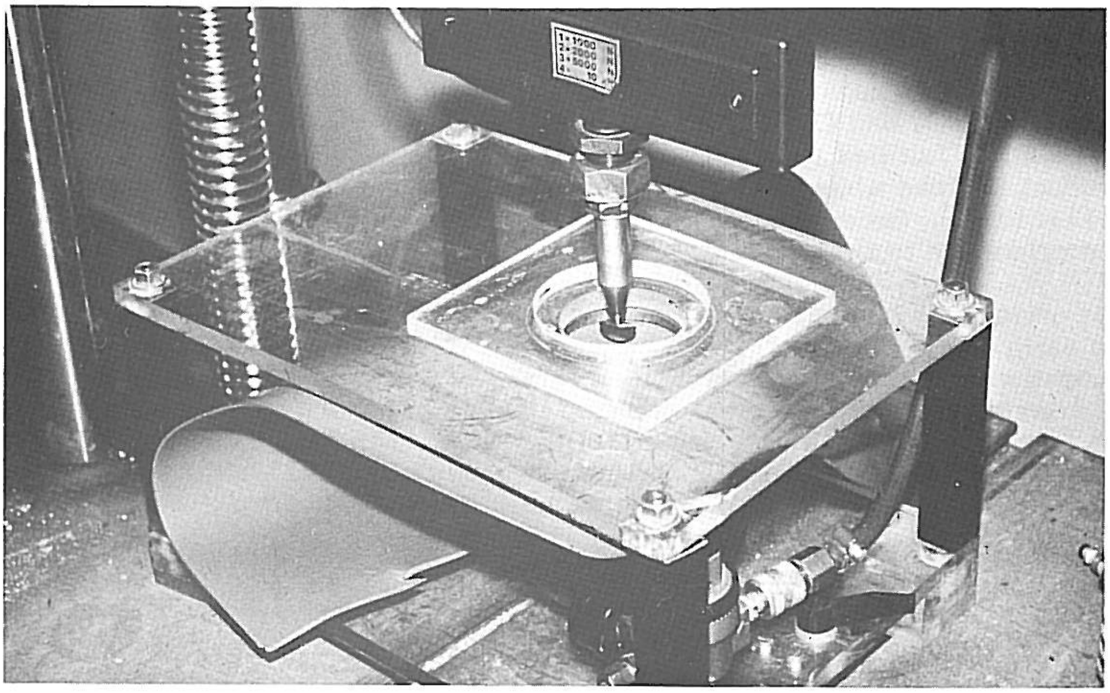

Fig. 3. NBI equipment for testing of puncture resistance

Results from laboratory tests

When the test results were studied in detail, it rapidly appeared that the most interesting property was cold flexibility. For the other properties tested, the results as such were interesting, but in most cases only minor changes in the measured properties were recorded after accelerated weathering. This also held true for the tensile strength and elongation at break. The following tendencies were recorded after accelerated weathering in the NBI apparatus:

- All materials had turned more or less yellowish
- the homogeneous materials had got a shrinkage from 1% to 4%, while the reinforced materials had shrunk from 0,1% to 0,3%
- for the materials A, D and E, the tensile strength went up and the elongation at break down. This meant that the materials got harder and "shorter"
- for the materials B and C, both tensile strength and elongation at break went down. These materials thus got harder, "shorter" and more brittle. This specially applied to material C
- for material F, the results were more special, and not particularly interesting in this connection
- the changes recorded after Xenotest weathering were smaller than after weathering in the NBI apparatus, Mark 1. The Xenotest was consequently not as severe as the NBI test.

The most interesting results were, as mentioned earlier, found for the cold flexibiliby properties. The results are summarized in Table 1.

The agreed test temperature was 243 K (-30 ^{o}C) as compared with the 253 K (-20 ^{o}C) specified in DIN 53361. All six products tested passed the test at 243 K (-30 ^{o}C) in fresh condition (not aged), with exeption of one single test piece of product F. After accelerated weathering in the NBI apparatus Mark 1, the results were more diversified. After 48 weeks, only the products A and D passed the test at 243 K (-30 ^{o}C) in aged condition, while the products E and F fulfilled the requirements at 248 K (-25 ^{o}C) and product B at 253 K (-20 ^{o}C). Product C broke while tested at 243 K (-30 ^{o}C) as well as all other temperature levels up to 273 K (0 ^{o}C). Because of the limited amount of aged material, there was no material left to continue the testing above this temperature.

There is obviously a connection between the poor results for product C on cold flexibility and the earlier mentioned increase in hardness and brittleness recorded for tensile strength and elongation at break. In general, there are good correlations between the results for tensile strength, elongation at break and cold flexibility, but the latter property seems to be the one best suited for differentiating the materials. The free shrinkage on accelerated weathering is providing additional information about a product's ability to function as a roofing material.

Results from natural weathering

In 1982 and 1983, comprehensive field studies of single-layer roofing membranes were carried through by the Norwegian Building Research Institute. The results were published in

Table 1

Cold flexibility by folding before and after accelerated weathering

Product	Thickness mm	Fresh material	Aged 16 weeks	Aged 48 weeks
All		Tested longitudinally as well as transversally, and with both surfaces outwards	Tested with exposed surface outwards, longitudinally and transversally	Tested with exposed surface outwards, longitudinally and transversally
A	1,0	243 K (-30 °C). Insignificant fold marking, no cracks or fissures	243 K (-30 °C). Very slight fold marking, no cracks or fissures	243 K (-30 °C). Clear fold marking, no cracks or fissures
B	1,0	243 K (-30 °C). Slight fold marking, no cracks or fissures	243 K (-30 °C). Slight fold marking, no cracks or fissures	243 K (-30 °C). All four test pieces broke 248 K (-25 °C). All four test pieces broke 253 K (-20 °C). Slight fold marking, but no cracks or fissures
C	1,0	243 K (-30 °C). Slight fold marking, no cracks or fissures	243 K (-30 °C). Slight fold marking, no cracks or fissures	243 K (-30 °C). All four test pieces broke 248 K (-25 °C). All four test pieces broke 253 K (-20 °C). All four test pieces broke 258 K (-15 °C). All four test pieces broke 263 K (-10 °C). All four test pieces broke 268 K (- 5 °C). All four test pieces broke 273 K (0 °C). All four test pieces broke
D	1,0	243 K (-30 °C). Insignificant fold marking, no cracks or fissures	243 K (-30 °C). Clear fold marking, no cracks or fissures	243 K (-30 °C). Clear fold marking, no cracks or fissures
E	1,2	243 K (-30 °C). Insignificant fold marking, no cracks or fissures	243 K (-30 °C). Fold marking in the membrane material, no cracks or fissures	243 K (-30 °C). More or less marked cracking in the top layer, no cracks in the bottom layer 248 K (-25 °C). Clear fold marking, no cracks or fissures
F	1,2	243 K (-30 °C). Insignificant fold marking, no cracks or fissures on 7 out of 8 test pieces. One test piece with tiny fissures at the bottom of the membrane (transversally). The fissures started in the small pits in the membrane at the crossing of the reinforcing fibres	243 K (-30 °). Clear fold marking in the membrane, no cracks or fissures on 3 out of 4 test pieces, a few small fissures in the surface on the last one transversally	243 K (-30 °C). All four test pieces broke 248 K (-25 °C). Clear fold marking, but no cracks or fissures

a report (4) presented by NBI and TPF (Takprodusentenes Forskningsgruppe, Norwegian Roofing Research Group). A few selected results will be presented here for three roofs in northern Norway.

Roof No. 1

This roof was covered in 1976 with roofing material C. The inspection was carried out in 1982 when the roof was 6 years old. Most of the roofing material was covered by gravel, and the samples were taken from the exposed parts on up-steps etc. On the free horizontal surfaces, the exposed membrane had got a brownish discolouration, partly spotwise.

The samples were checked for tensile strength, elongation at break and cold flexibility. The results for tensile strength and elongation at break did not give any significant information about possible changes in the material. The results from the cold flexibility tests are given in Table 2.

Table 2

Cold flexibility, roof No. 1

Test temperature	Discolouration	Observations
253 K (-20 °C)	Brown	Fissures in the surface
	Light brown	One test piece broke, others OK
258 K (-15 °C)	Brown	Fissures in the surface
	Light brown	One test piece broke, others OK
263 K (-10 °C)	Light brown	One test piece broke, one with fissures, two OK
268 K (- 5 °C)	Light brown	Small fissures in a brown spot, rest OK

The test results are very diversified. Anyhow, comparision with Table 1 shows a marked difference from the results obtained for fresh material C and better correlation with the results for 48 weeks of accelerated weathering.

Roof No. 2

This roof was also covered in 1976 with roofing material C. The inspection was j ade in 1983 when the roof was 7 years old. Samples were taken from the exposed parts, both horizontal and vertical. Here too, the membrane material had got a brownish discolouration.

The results from testing of tensile strength and elongation at break did not give any clear information. The results from the cold flexibility tests are given in Table 3.

Table 3

Cold Flexibility, roof No. 2

Sample position on roof	Test temperature	Observations
Horizontal	263 K (-10 °C)	All test pieces broke
	268 K (- 5 °C)	No cracks or fissures
Vertical	248 K (-25 °C)	All test pieces broke
	253 K (-20 °C)	No cracks or fissures

Here too, results can be compared with those for material C in Table 1. Specially worth noting is the difference between vertical and horizontal position.

Roof No. 3

This project was made with material E in 1975, and was 8 years old when inspected in 1983. A sample was taken from an exposed vertical part. There was no discolouration of the membrane material. The cold flexibility testing was carried out on the sample, and there were no cracks or fissures at 243 K (-30 °C).

Concluding remarks

The possible correlation between accelerated weathering and natural weathering is always an interesting point. With the NBI apparatus Mark 1, it is usually assumed that the acceleration factor is from 10 to 15. This means that 16 weeks should correspond to about 5 years of natural weathering and 48 weeks to about 15 years. This is of course only valid for the exposed parts of a roof covering. Under the gravel used to load loose-laying roof membranes, other ageing factors may be of greater interest.

The exposed part of the 8 year old roofing material E used on roof No. 3 was found to be in perfect condition when tested on cold flexibility. This corresponds very well with the results for 16 weeks of accelerated weathering in Table 1, equal to roughly 5 years of natural exposure. The material on roof No. 3 had obviously not reached the stage of the same material after 48 weeks of accelerated weathering, corresponding to about 15 years of natural weathering.

The results for the material C on the 6 and 7 years old roofs Nos. 1 and 2 do also fit well into the picture. In both cases, the material has obviously passed the point equal to 16 weeks of accelerated weathering, but not reached the stage at 48 weeks. Observations at intermediate points of time would have been interesting, but are unfortunately not available.

The observed discolouration on natural exposure can so far not be fully explained. It is possible that contamination from air pollutants is taking part in the ageing processes.

Anyhow, the main tendencies observed for material C are the same on accelerated as well as natural weathering. The material C erodes, gets harder and more brittle, and gets after some time of exposure a marked reduction in cold flexibility properties. This could be concluded from the accelerated weathering test in less than one year, and it was not necessary to wait for 6 or 7 years of practical experience. This proves that accelerated weathering tests can be of great value.

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Accelerated and Natural Weathering of Wooden Windows with Organic Coatings

by

Tore Gjelsvik, technical physicist MNIF, MNFS

Abstract

Wooden windows coated with various paint and stain systems have been tested in the laboratory. The first series covered 60 windows 0,5 m x 0,5 m and 17 coating systems. The test equipment was the apparatus for accelerated weathering of building materials and components, Mark 2 (1).

To study the correlation with natural exposure, full scale tests were also started.

The properties studied include general appearance, chalking, erosion, cracking, flaking and resin exudation. The wood quality has appeared to be important, and partly masks the result of the ageing process. Anyhow, the same main tendencies are observed for accelerated and natural weathering when up to 27 weeks laboratory testing is compared with 2 years natural exposure.

Résumé

On a fait des essais dans le laboratoire avec les systèmes différentes de peinture et teinture sur les fenêtres du bois. La première série a compris 60 fenêtres 0,5 m x 0,5 m et 17 systèmes de couverture. L'équipment utilisée était l'appareil pour étudier la tenue aux intempéries des matériaux et éléments du bâtiments, Type 2 (1).

Pour étudier la correlation avec l'exposition naturelle, les éssais en pleine dimension sont aussi établis.

Les propriétées étudiées s'embrassent l'apparence générale, surface calcaire, érosion, craquelage et fissuration, écaillement et exsudation des résines. La qualité du bois se montre comme très importante, et masque partiellement les résultats de la vieillissement. Toutefois, les mêmes tendences principales sont observées quand 27 semaines d'exposition accelerées en laboratoire sont comparées avec une et deux années d'exposition naturelle.

Introduction

The traditional way of carrying out accelerated ageing tests is by using a commercially available test equipment like an Atlas Weather-Ometer. This type of equipment can be quite useful, but has, on the other hand, obvious limitations. First of all it can only accomodate small test pieces, usually up to about 50 mm x 100 mm. Secondly, the test cycle normally comprises only light, heat and moisture.

In the early 1960-s, a special apparatus for accelerated weathering of building materials and components was designed and built at the Trondheim Division of the Norwegian Building Research Institute. One important point in this connection was to be able to test larger samples than in commercially available types of equipment. A second point was to get a sufficiently rapid ageing cycle. The final result was the special apparatus, Mark 1, that was completed in 1965. This apparatus had four test openings 1 m x 1 m and could take samples up to about 0,9 m x 0,9 m. Tests with building sealants indicated an acceleration factor of 12 to 15 times.

A more detailed description of the apparatus and test cycles has been given before (1), and shall not be repeted here.

Test equipment

Based on the experiences with the first type of equipment, a second one was completed i 1979. The Mark 2 is about four times the size of Mark 1, and can take samples up ut 1,5 m x 2,5 m. The basic features will appear from Figure 1. This large size test equipment consists of a circular central chamber (E) and three fixed boxed for the climatic strains (A, B and C). The central chamber has got four test openings where the test pieces are mounted. The interior of this chamber is conditioned at 296 ± 2 K (+23 ± 2 °C) and 65 ± 2% RH. The central chamber is most of the time in a resting position, but is with certain intervals of time moved a quarter turn (90°). The test pieces are in that way subjected to constant climate 296 ± 2 K (+23 ± 2 °C) and 65 ± 2% RH on one side, and the following test cycle on the other side:

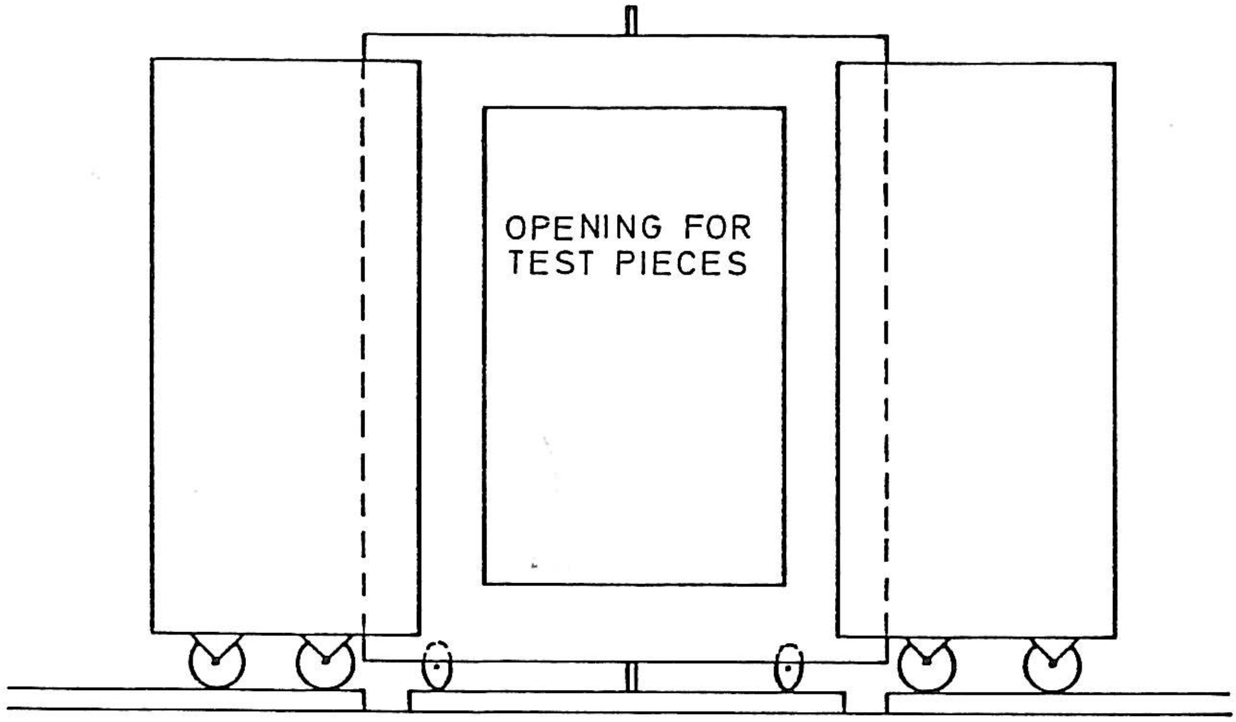
A. Radiation from sun light lamps of the type Osram Ultra Vitalux GUR 53 300 W or similar and simultaneous heating to an elevated temperature. Radiation 1900 W/m^2 (input)

B. Wetting with a spray of demineralized water, 15 ± 2 l/m^2h, temperature 291 ± 5 K (18 ± 5 °C)

C. Cooling and freezing to a temperature of 253 ± 5 K (-20 ± 5 °C)

D. Thawing at room temperature 296 ± 2 K (23 ± 2 °C) and 40 ± 10% RH, with possibilities for inspecting and changing the samples without stopping the test apparatus.

The resting time in each position is normally one hour. This gives a maximum black panel temperature of 348 ± 5 K (75 ± 5 °C) in position A, and a total time of four hours for each full cycle. The apparatus is operating continously.



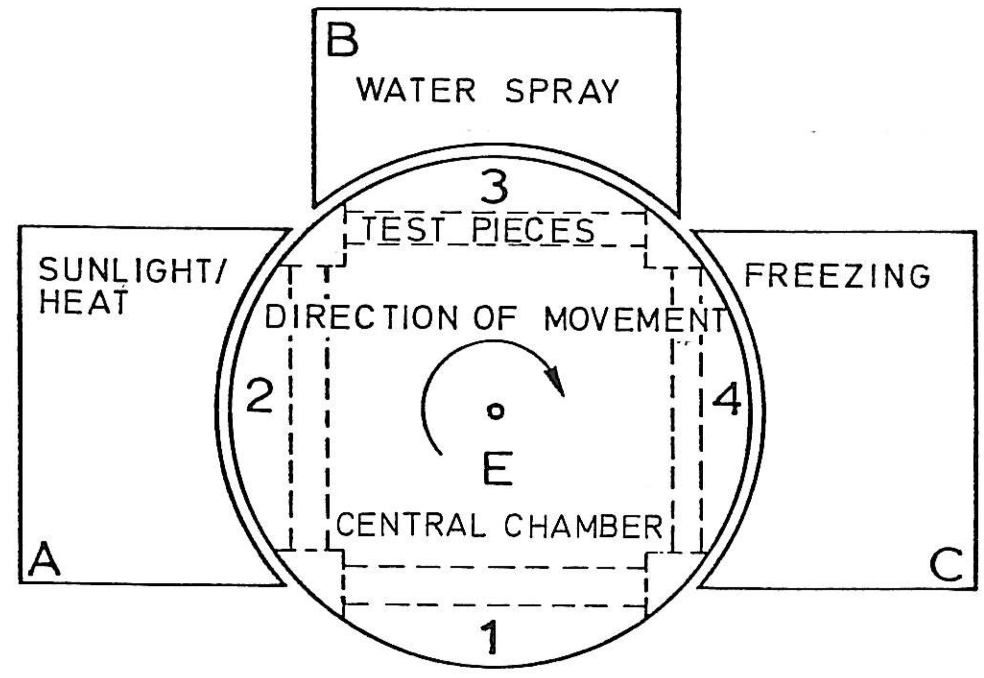


Fig. 1. Principal drawing of apparatus for accelerated weathering, Mark 2

Planning and running of tests

The background for the new test equipment, Mark 2, was inquieries from the woodworking and paint industries in Scandinavia about full scale tests with surface treated wooden windows. The industrial partners also took part in the planning and steering of the tests. It was considered essential to test normal windows with normal details. After a closer examination of the problems, it was finally decided to use windows in size 0,5 m x 0,5 m. This would give normal corner joints, and possibilites for all types of normal movements across the sections. The partly loss of movement in the longitudinal direction was considered less important.

The use of windows 0,5 m x 0,5 m external frame would make it possible to fill up the test apparatus completely. The four test openings 1,5 m x 2,5 m would take 15 windows each, and permit sumultaneous testing of a total of 60 windows. It was decided to use four windows for each conifer system, two of fir and two of spruce, and two windows for each teak system. During the detailed planning, some more two windows systems were introduced. The final result was 60 windows, divided on 13 systems of four windows each and four systems of two windows each. Figure 2 shows the test apparatus with the windows installed.

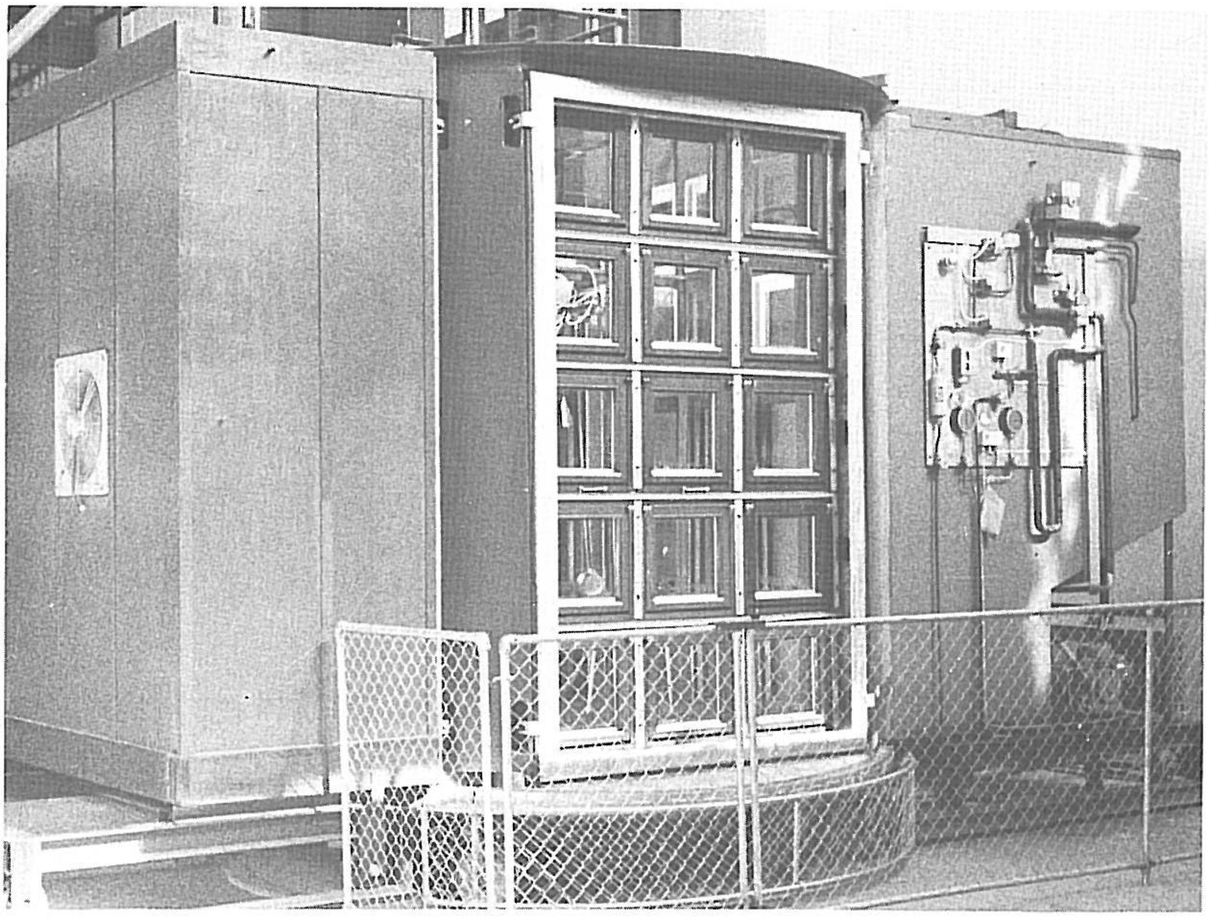


Fig. 2. View of accelerated ageing apparatus, Mark 2, with surface coated test windows installed

In the final report (2), the surface treatment systems are numbered from 1 to 17, and given a general description without mentioning brand names. The systems are split into the following five main groups:

1. Alkyd systems for conifer
2. Acrylic systems for conifer
3. Emulsion systems (alkyd/acryl) for conifer
4. Pressure impregnation systems for fir
5. Alkyd systems for teak.

Some details are found in Table 1.

For the first series of tests, the resting time of the apparatus in each position was set at three hours instead of the normal one hour. The reason for this change was to let the windows have a possibility to accumulate humidity from the inside climate. More details about the running of the tests are found in the final report (2).

Table 1.

Survey of the coating systems

System number	System type	Wood	Pretreatment	Treatment outside	Treatment inside
1	Alkyd	Fir Spruce	Impregnation Dipping	Two coats of stain with brush	Three coats of stain with brush
2	Alkyd	Fir Spruce	Impregnation Dipping	Two coats of stain	Two coats of stain
3	Alkyd	Fir Spruce	Impregnation Dipping	Two coats of paint	Two coats of paint
4	Alkyd	Fir Spruce	Impregnation Dipping	Two coats of paint	One coat of stain, one of laquer
5	Alkyd	Fir Spruce	Impregnation Dipping	Two coats of stain by spraying	Two coats of stain by spraying
6	Alkyd	Fir Spruce	Impregnation Dipping	Two coats of stain by dipping	Two coats of stain by dipping and one coat of laquer on frames by spraying
7	Alkyd	Fir Spruce	Impregnation Dipping	One coat of stain by dipping and one coat by spraying	One coat of stain by dipping and one coat by spraying
8	Alkyd	Fir	Impregnation	Two coats of stain by spraying	One coat of stain by spraying
9	Acryl	Fir Spruce	Dipping Dipping	Two coats of stain by dipping	Two coats of stain by dipping and one coat of laquer by spraying
10	Acryl	Fir Spruce	Impregnation Dipping	Two coats of paint	Three coats of paint
11	Acryl	Fir Spruce	Dipping Dipping	Two coats of stain by dipping	Two coats of stain by dipping and one coat of laquer on frames by spraying
12	Acryl	Fir Spruce	None None	One coat of stain by dipping and one coat of laquer by spraying	One coat of stain by dipping and one coat of laquer by spraying
13	Acryl	Fir Spruce	Dipping None	Two coats of stain	Two coats of stain
14	Emulsion	Fir Spruce	Impregnation Dipping	Two coats of alkyd/acryl emulsion	Two coats of stain
15	Pressure impregn.	Fir	None	Pressure impregnation and boiling in pigmented oil, followed by brushing	As outside, followed by brushing and one coat of laquer by spraying
16	Teak	Teak	None	Four coats of special oil by brush	Four coats of special oil by brush
17	Teak	Teak	None	Three coats of special oil by brush	Three coats of special oil by brush

The windows were inspected at regular intervals during the running of the tests. In addition to the visual observations, the following properties were checked at the end of the tests: General appearance according to Nordic practice, chalking to ASTM D659-74, erosion to ASTM D662-44 (75), cracking to ASTM D661-44 (75), flaking to ASTM D772-47 (75) as well as resin exudation. For each property, a scale from 1 to 10 was used, where 10 was the best. It is usually assumed that retreatment is necessary when the general appearance has reached the range from 5 to 6.

To study the correlation with natural exposure, full scale tests were started at two different sites. One was a group of flats outside Bergen, on the Norwegian west coast. Here the kitchen windows were used for the tests, as these were all on the first floor and equally exposed to the west/soutwest. The windows consisted of one fixed and one openable part. They were made of fir, and were given the same surface treatment as the conifer windows for the laboratory tests. The colour was, however, specified as "chestnut brown". For this reason, two of the 15 conifer systems had to be changed so much that the quality was not the same as the one used for the laboratory tests. For these two systems, no real comparisons can be made.

The second natural exposure project was an office building in Oslo, where the two teak systems were used.

All windows on natural exposure were inspected after one and two years respectively.

Results from the ageing tests

The results from the inspections of the windows used in the accelerated ageing tests have to be presented separately for each coating system. There are, however, a number of general results that are more or less independent of the coating system.

First of all, it has appeared that the wood quality has a marked influence on the results. It was expected that the visual damage as cracking and flaking should first appear at the bottom sash and frame members. This did not hold true. On the contrary the damage seemed to be more or less randomly distributed on the bottom, top and sides. The wood had a number of small knots, and also some larger knots, and this had a marked influence on resin exudation and knot marks. Also other types of wood faults had a similar influence.

The way the individual window members had been cut out of the timber, also proved to have a marked influence on the possibilities for movement and subsequent cracking, for instance in the corner joints. In general, corner joints tended to open up, and more on windows with eroded coating systems than on those better preserved.

Cracking did also appear in the wood, partly as faint cracks and partly as wider cracks, but there was no indication of rot formation. Cracking in the wood did also result in cracking of the coating. There was no difference between spruce and fir on this point.

Finally, it was noted that the weight of the windows did not give any real indication of the ageing stage. It was expected that the windows should gain in weight due to moisture migration from the inside. In fact, the opposite occurred. The windows dried out so well in the solar radiation position that this overruled the wetting from inside and outside. As a consequence, one hour in each resting position instead of three hours has been recommended for future tests.

An example on the results of the final inspection is given in Table 2. This table covers the systems number 9 and 10, and do illustrate fairly well the deviations obtained due to varying wood properties. For details on other systems, reference is made to the final report (2). The same applies to detailed results from the natural exposure.

Table 2

Final inspection of test windows, system Nos. 9 and 10

R = Sash, K = frame, G = spruce, F = fir

System No	Window		General appearance	Chalking	Erosion T	L	R	B	m	Cracking T	L	R	B	m	Flaking T	L	R	B	m	Knot marks T	L	R	B	m	Remarks
9	G1	R	9,5		9,5	9,5	9,5	9,5	9,5	9	9	9	9,5	9,1	8[1]	10	10	10	9,5						1) Slight flaking
		K			9,5	9,5	9,5	9,5	9,5	8	9	9	9	8,8					10						
	G2	R	9,5(9 knots)		9,5	9	9,5	9,5	9,4	9,5	8	6	9	8,1	9,5	10	10	9	9,6	10	9,5	10	10	9,9	
		K			9,5	9	9,5	9	9,3	9,5	9,5	9	9	9,3	10	10	10	9,5	9,9						
	F1	R	9 (8 knots)		9,5	9	9,5	9	9,3	7	6	6	10	7,3	10	9	10	9	9,5	10	8	10	9	9,3	
		K			9,5	9,5	9,5	9	9,4	9	6	6,5	7	7,1	9	9	10	9	9,3	10	8	10	9	9,3	
	F2	R	8,5 (7 knots and resin)		9,5	9,5	9,5	10	9,6	8	6	6	7	6,8	10	9,5	9,5	10	9,8	9	9	7[2]	9	8,5	2) Knots and resin exudation
		K			9,5	9,5	9	8,5	9,1	7,5	6	5	5	5,9	10	9,5	9,5	9	9,5	8	10	10	8[3]	9	3) Resin exudation
10	G1	R	8 (7 knots)							8	8,5	8	8	8,1	8	8	9	9	8,5						
		K								8	6,5	6	8	7,1	8	9	7,5	7	7,9						
	G2	R	8(7,5 knots)							6	6,5	9	7	7,1	8,5	8	9,5	9	8,8						
		K								8	7	6	7	7	9	9,5	9	9	9,1						
	F1	R	8(7,5 knots)							5	5	5	7	5,5	9	8	8	9	8,5						
		K								7,5	6	6,5	7	6,8	8	6,5	9	7	7,6						
	F2	R	8,5(7,5 knots)							6	7,5	6,5	7,5	6,9	10	9	9,5	10	9,6						
		K								6	6	7,5	6	6,4	8	7,5	7	7	7,4						

Correlation between accelerated ageing and natural exposure

The possible correlation between the results from accelerated ageing and natural exposure is of course a very interesting question. In Table 3, data on general appearance have been placed together for 27 weeks of accelerated ageing as compared with one and two years of natural exposure. The systems number 2 and 8 have been excluded, as it was not the same quality supplied for natural and accelerated ageing. For the other systems, the main tendencies are roughly the same. The products are not appearing in exactly the same order in the judgements, but this is not surprising. The deviations can be due for instance to differences in the wood substrates and differences in the climatic conditions. Some of the deviations are also probably due to a somewhat too high temperature during the accelerated ageing. For this reason the resting time of the apparatus in each position has been changed from three hours to one hour.

To get a real picture of the relationship between accelerated and natural ageing, it is also necessary to have more observations than those compared in Table 3. The general appearance alone is not sufficient to characteristize a system. Data on other properties

Table 3

Comparison of 27 weeks accelerated ageing with one and two years natural exposure

System	System	General appearance						
No.	type	Accelerated ageing				Natural exposure		
		F I	F II	m	Remarks	1 year	2 years	Remarks
1	Alkyd	5,5	5,5	5,5	Erosion	9	7	Flaking
3	Alkyd	9	8,5	8,8		9,8	9,5	
4	Alkyd	9	9,5	9,3		7,8	7,5	
5	Alkyd	9	9	9		8	7	Flaking
6	Alkyd	8	8	8		9	8,5	
7	Alkyd	6	6	6		8	7,5	
9	Acryl	9	8,5	8,8		9	8,5	
10	Acryl	8	8,5	8,3		9,8	9	
11	Acryl	9	9	9		9	8,5	
12	Acryl	8,5	6,5	7,5	Spread in results	8	7,5	
13	Acryl	6,5	6,5	6,5		7	6,8	
14	Emulsion	8,5	9,5	9		9,5	9,5	
15	Pressure Impregnation	6,5	6,5	6,5		6,8	6,5	
16	Teak	2	2	2[1)]	Fine cracking, loss of adhesion	10	9,5	Fine cracking, flaking, erosion
17	Teak	2	2	2[2)]	Ditto	7	6	Ditto

1) Exposure time 18 weeks
2) Exposure time 9 weeks

should also be included. Finally, observations should be taken at more points of time than those in Table 3. It is not sufficient to compare 27 weeks of accelerated ageing with one and two years of natural exposure, especially not when the acceleration factor is high. Before final conclusions can be drawn, more tests are needed. At present the results have to be considered only as indications on what can occur in practice.

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Accelerated Weathering and Outdoor Exposure of Glass-fibre Reinforced Polyester (GUP)

by

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Abstract

Ten types of glass-fibre reinforced polyester sheets have been tested in the laboratory, using the special apparatus for accelerated weathering of building materials and components, Mark 1. The same materials have also been on natural exposure at two different sites in Norway. Total testing time was 252 days in the laboratory and $5\frac{1}{2}$ years of natural exposure.

The bending stiffness was chosen as the interesting factor to study the effect of the ageing.

The comparisons show that the two outdoor exposure sites do not give the same results, and that the ranking of the materials differs. The recorded changes in the bending stiffness can, however, be considered as acceptable. The differences recorded between outdoor exposure and accelerated weathering are not more significant than the differences between the two outdoor exposure sites.

Résumé

On a fait des essais dans le laboratoire avec dix types de plaques de polyestres renforcées avec des fibres de verre. L'équipement utilisée était l'appareil pour étudier la tenue aux intempéries des matériaux et éléments du bâtiments, Type 1. Les mêmes matériaux sont aussi sujets à l'exposition naturelle à deux différentes localitées dans la Norvège. Le temps d'essai total était 252 jours dans le laboratoire et $5\frac{1}{2}$ années à l'expostion naturelle.

La rigidité de fléxion était choisi comme la propiété intéressante pour étudier les effets de la vieillissement.

Les comparaisons indiquent que les deux localitées de l'exposition naturelle ne donnent pas les mêmes résultats, et que les materiaux montrent à l'ordre différente. Les changements observées à la rigidité de fléxion peuvent toutefois être considerées comme acceptables. Les différences observées entre l'exposition naturelle et l'exposition accelerée en laboratoire ne sont pas plus significantes que les différences entre les deux localitées de l'exposition naturelle.

Introduction

In the early 1960-s, a special apparatus for accelerated weathering of building materials and components was designed and built at the Trondheim Divison of the Norwegian Building Research Institute. The apparatus as such has been described in earlier publications (1), (2), and details on the equipment and test cycle shall not be repeated here. Reference is made to the publications quoted.

The accelerated weathering apparatus has been used since 1965, and results are found in a number of reports from the Norwegian Building Research Institute. The interesting questions about acceleration factor and correlation with natural exposure were in the first hand solved by comparing results from accelerated testing of building sealants with experience collected during field studies in Scandinavia. With the sealants, the correlation seemed to be good, and indicated an acceleration factor between 10 and 15. These figures have later on been used as the basis for the evaluation of results from tests with other materials and components.

Testing of GUP materials

In 1974, the Trondheim Division of the Norwegian Building Research Institute started a series of tests with glass-fibre reinforced polyester materials (GUP). The tests arose from a general interest in such materials, but ended up with comparative testing of a number of materials on natural exposure as well as accelerated weathering. This gave a new opportunity to collect information about the correlation of the accelerated weathering with natural exposure.

The testing was a joint venture sponsored by three partners:

- A/S Jotungruppen, who supplied the polyesters and other materials needed to make up the samples
- SINTEF, section 16, who worked as consultants on the formulations and the preparation of the samples
- NBI, Trondheim Division, who did the practical work, including the exposing, testing and reporting.

The tests were started in 1974 and finished in 1979. The laboratory tests were run for up to 252 days in the apparatus for accelerated weathering, Mark 1, while the natural exposure went for a total of $5\frac{1}{2}$ years.

The polyesters supplied by A/S Jotungruppen were of four different types:

Polyester 1 orthoptalicacidbased

Polyester 2 isoptalicacidbased

Polyester 3 selfextinguishing type, based on chlorinated additives and antimonytrioxide

Polyester 4 selfextinguishing type with chlorine built into the molecule structure

The polyesters were partly used unfilled and partly filled. The samples were made as laminates with a surface coating of non-reinforced material backed by three layers of glassfibre reinforced material. On one material, the non-reinforced top layer was substituted with two coats of a gelcoat. A total of ten different types of GUP sheet were produced , and numbered as follows:

GUP 1	Polyester 1, unfilled
GUP 2	Polyester 1, filled with 35% silica
GUP 3	Polyester 2, unfilled
GUP 4	Polyester 2, filled with 35% silica
GUP 5	Polyester 3, unfilled
GUP 6	Polyester 3, filled with 35% silica
GUP 7	Polyester 4, unfilled
GUP 8	Polyester 4, filled with 35% silica
GUP 9	Polyester 1, filled with 35% dolomite
GUP 10	Polyester 1, unfilled, gelcoat as top layer.

The sheets were produced about 850 mm by 1200 mm, and cut to get the number of test pieces needed for the tests. Three different sizes of test pieces were made:

A 150 mm x 300 mm, for natural exposure studies

B 100 mm x 450 mm, for study of dimensional changes due to changes in relative humidity

C 100 mm x 200 mm, for accelerated weathering.

The natural exposure was carried out at two different exposure sites. One was at the top of the Tyholt hill in Trondheim, 113 meters above sea level. The climatical conditions at this spot is fairly well representative for the Trondheim region, with its intermediate and typically changing climate. The second exposure site was at Skarsøy in the Møre region on the Norwegian west coast. This place was at the sea shore, 3 meters above sea level, and with a typical sea climate. The samples were mounted on racks, facing the south, and at an angel of 38 ^{o} with the horizontal surface. The exposure started in the summer 1974, and the samples were taken down, inspected and checked at certain intervals of time up to the end of 1979. The total exposure time was about $5\frac{1}{2}$ years.

The accelerated weathering was started in 1974 and went on for 252 days. The samples were mounted in the apparatus, hanging in a vertical position. Also the samples on accelerated weathering were taken down and checked at certain points of time.

Two types of measurements were taken on all samples subjected to weathering. One was to weigh them, to calculate the change in weight on time. The second was to measure the bending stiffness. This property was selected as a basis for judging the ageing stage of the materials. The test pieces were subjected to a certain deformation, and the force needed to produce the specified deformation was noted as a measure of the stiffness.

Test results

The weight changes recorded are given in Table 1 for accelerated weathering as well as natural exposure. For the accelerated weathering, data are given at four different points of time, while on natural exposure the data are for $5\frac{1}{2}$ years of exposure only.

All changes occured as weight losses, as could be expected. Surprisingly, however, the weight losses were greater on natural exposure than on accelerated weathering. A possible explanation is that remaining monomeric material is gradually lost on natural exposure, while the same is bound in a rapid final cure on accelerated weathering. Worth nothing is also the lack of correlation between the two natural exposure sites. Anyhow, all weight changes must be considered as fairly small.

Table 1

Recorded weight loss on accelerated weathering and natural exposure, %

Material number	Accelerated weathering, days				Natural exposure, 5½ years	
	112	168	196	252	Skarsøy West coast	Tyholt Trondheim
1	0,05	0,13	0,27	0,33	1,6	4,1
2	0,18	0,24	0,28	0,30	1,5	2,2
3	0,10	0,16	0,26	0,32	3,7	3,5
4	0,17	0,25	0,30	0,38	2,5	2,2
5	0,24	0,30	0,41	0,47	1,1	3,6
6	0,07	0.15	0,28	0,32	1,9	2,3
7	0,37	0,54	0,79	0,84	4,5	4,8
8	0,22	0,29	0,36	0,37	4,5	3,7
9	0,10	0,20	0,35	0,36	3,0	3,8
10	0,41	0,42	0,56	0,57	4,9	3,8

The changes in recorded bending stiffness will appear form Table 2. In the first column is given the forces in Newton needed to produce the specified deformation of the ten different materials before they were subjected to any kind of weathering. In the following columns, the remaining bending stiffness is given in percent of the original stiffness for different weathering places and stages.

As it will appear from Table 2, the adding of fillers to the polyester materials is normally increasing the bending stiffness. In most cases, the fillers also seem to have a positive influence on the remaining bending stiffness after ageing.

When the results are studied in detail, some interesting observations can be made. On accelerated weathering, all ten materials get their bending stiffness reduced more or less systematically. On natural exposure, on the other hand, most of the materials increase their bending stiffness, and only two out of ten get a reduction. The effects are, however, not the same at the two different natural exposure sites. At the Tyholt station in Trondheim the materials come out in the following order: 2 - 3 - 5 - 1 - 6 - 9 - 4 - 7 - 10 - 8. At the Skarsøy site on the west coast the order is: 1 - 2 - 4 - 6 - 7 - 9 - 5 - 3 - 10 - 8.

When possible correlation between accelerated weathering and natural exposure shall be sought, the acceleration factor in the laboratory equipment must be taken into account. This factor is normally expected to be between 10 and 15. It is then obvious that it is the results at 112 days of accelerated weathering that has to be compared with the 5½ years of natural exposure.

At 112 days accelerated weathering the average remaining bending stiffness of the ten materials is 76%, as compared with 109% at the Skarsøy west coast natural exposure site and 120% at the Tyholt Trondheim site after $5\frac{1}{2}$ years of natural exposure. The figures for the individual materials do not add much to the general picture.

Table 2

Remaining bending stiffness after accelerated weathering and natural exposure

Material number	Force needed to produce specified deformation N	Remaining bending stiffness, %					
		Accelerated weathering, days				Natural exposure $5\frac{1}{2}$ years	
		112	168	196	252	Skarsøy West coast	Tyholt Trondheim
1	135	80	60	55	45	135	130
2	212	80	60	70	60	125	145
3	80	65	60	50	30	100	145
4	312	60	70	65	65	125	110
5	73	60	60	60	45	105	140
6	148	70	85	70	60	125	120
7	77	95	50	50	45	110	110
8	167	90	65	65	50	75	85
9	118	80	50	45	45	110	115
10	105	80	50	45	40	80	100
Average	143	76	61	58	49	109	120

The binding stiffness is reduced on accelerated weathering and increased on natural exposure. The explanation to this result is quite simple. On accelerated weathering, the temperature cycling leads to a gradual loss of adhesion between the polyester and the reinforcing glass fibres, resulting in the observed reduction in bending stiffness. This phenomenon is well known from the literature (3). On natural exposure, this phenomenon does not occur to the same extent. Here the dominating factor seems to be the normal increase in stiffness of the polyester material itself on weathering and ageing.

As there are no results from natural exposure for more than $5\frac{1}{2}$ years available, there is nothing to compare the results of 168, 196 and 252 days of accelerated weathering with. The lastmentioned results indicate a further loss in bending stiffness, but this should only be taken as an indication.

Conclusions

The weather resistance of all the ten GUP materials tested must be considered as good. The weight changes recorded are fairly small, and the changes in bending stiffness acceptable.

The comparisons show that the two outdoor exposure sites do not give the same results, and that the materials come out in a different order. The differences recorded between the outdoor exposure and accelerated weathering are not more significant than the differences between the two outdoor exposure sites. The results indicate, moreover, that GUP as a composite material is probably not the most useful material for comparative weathering studies.

References

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Long Time Practical Experience with Sealed Glazing Units in Severe Norwegian Climate

by

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Abstract

Sealed glazing units installed in buildings in Central and Western Norway in the twelve years period from 1951 to 1963 have been inspected three times, in 1963, 1973 and 1983 respectively. At the time of the final inspection, the units were from 20 to 32 years old.

A total of 1769 units is covered by the study, divided on ten different brands. The studies include visual inspection as well as dew point measurements.

The material has been treated statistically and shows quite clearly the influence of a number of factors on the practical service life of sealed glazing units from the "classical" period. The conclusions are first of all valid for the units, windows and glazing technique from that period, but connections to present-day technology can also be drawn.

Résumé

On a fait des études sur les doubles-vitrages scellées, installées dans les bâtiments à la Norvège Centrale et Occidentale pendant la période de 1951 á 1963. Les vitrages sont été inspectèes trois fois, en 1963, en 1973 et en 1983. La dernière fois, les double-vitrages avaient de 20 à 32 années.

Un nombre total de 1769 volumes est couvert par les études, divisé à dix types différents. Les observations embrassent inspection visuelle aussi bien que mesurage du point de rosée.

Les résultats sont été traité d'après les vues statistiques, et indiquent clairement l'influence d'un nombre des facteurs sur la vie de service pratique des doubles-vitrages scellées de la période "classique". Les conclusions sont avant tout valables pour les vitrages, les fenêtres et le technique d'installation de cette pèriode, mais les relations avec la technique présente peuvent aussis être tirées.

Introduction

Sealed glazing units are manufactured with dry air or gas between the panes and a gas- and vapour-tight seal along the edges. The practical service life of such units is obviously dependent upon the efficiency of the edge seal. A high water vapour diffusion rate or a rapid breakdown of the edge seal will reduce the practical service life of units considerably.

Much work has been carried out over the years to make it possible to forecast the expected service life of sealed glazing units. The traditional way is by accelerated ageing tests in the laboratory. The value of such tests has been disputed. Anyhow, they usually constitute the most important part of the basis for a rapid evaluation of new types of unit.

The alternative to laboratory testing is to collect information from units on natural exposure. To follow up units in the field is, however, a time-consuming job. A more rapid and effective way is by making systematical field studies on units of different age.

NBI field studies 1963, 1973 and 1983

The most comprehensive field study carried out by the Norwegian Bulding Research Institute is the one known as the West Coast Field Study 1963. This study covered a total of 2040 sealed glazing units, divided on ten different brand names and installation years from 1951 to 1963. The study covered visual inspection as well as measurement of dew point. Detailed results are found in the report (1).

Later on, the same units have been inspected again in 1973 and 1983. In 1963, a total of 2040 units was included. In 1983, the number of counting units had been reduced to 1769. The difference is coming from a couple of buildings wrecked down and removed, several cases of remodeling and change of windows, as well as units broken by accidents. Only units that could be followed through from 1963 to 1983 have been taken as counting. These were from 20 to 32 years old at the final inspection.

Results

The units studied covered a total of ten types or brands. Included was one type of all-glas unit with fused edge seal in Group I, two types of units with direct glass-to-metal seal in Group II and seven types with glued edge seal in Group III. Details are found in Table 1 and Figure 1. The distribution of the counting units is shown in Table 2.

The types of damage recorded in 1973 and 1983 were the same as in 1963. Included were observations of visible condensation and scumming at the time of inspection, measured dew point above (or at) the critical limit, visible cracks in the glass as a result of condensation, visible cracks in the metal seal as well as deflection of the metal seal. Cracks in the glass, cracks in the metal seal and deflection of metal seal were, however, only recorded in connection with visible condensation or dew points above critical limit. For practical reasons, it was found convenient to distinguish between only two types of damage when the material was treated in detail:

1. Visible concensation and scumming
2. Dew point above the critical limit.

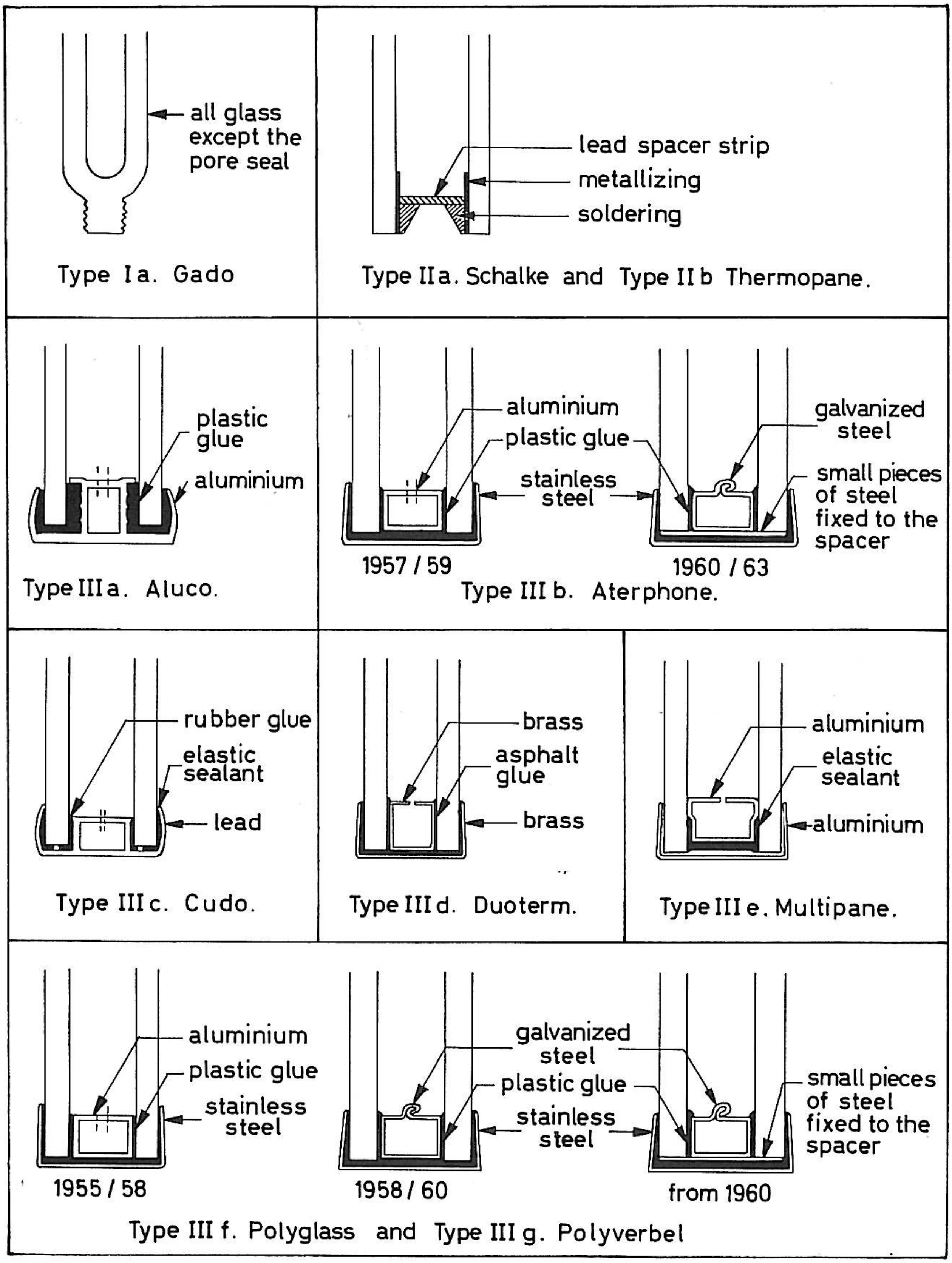

Fig.1. Cross-sections of the edge seal of the different types of unit

Table 1

Classification of the products studied

Group	Type of seal	Brand name
I	All-glass	Gado
II	Glass-to-metal	Schalker Thermopane
III	Glued	Aluco Aterphone Cudo Duoterm Multipane Polyglass Polyverbel

Table 2

Distribution of units on different types and year of installation

Type of unit	Year of installation												Total
	1951	-52	-53	-54	-55	-56	-57	-58	-59	-60	-61	62/3	
Gado								2					2
Schalker				56	35	22		43	47	23	61	58	345
Thermopane	2	4	3	25	16	35	107	87	46	100	100	65	590
Aluco												9	9
Aterphone									9			1	10
Cudo									40	126	53	45	264
Duoterm										3	13		16
Multipane										18	1	5	24
Polyglass					1		9	8	44	34	13	28	137
Polyverbel						6	163	78	59	38	28		372

In addition, recordings on replacement of units were sorted out. On this basis, damage frequencies have been calculated for all combinations of type of unit and year of installation. The results will appear from Table 3. In each counting square in the table, three figures are given. The one at the top is for 1963, the central figure for 1973 and the one at the bottom for 1983.

A closer study of Table 3 reveals that the results are very diversified. Some of the brands seem to have had edge seals with such poor durability that there is nothing left after a period from 10 to 20 years of natural exposure. Others have served much better, and the best results are obviously found for the glass-to-metal seal units Schalker and Thermopane as well as the 1961/63 productions of the glued types Polyglass and Polyverbel. The latter results are closely related to wellknown changes in the products.

Table 3

Damage frequencies, %

Type of unit	Year of installation												Average all years
	1951	-52	-53	-54	-55	-56	-57	-58	-59	-60	-61	62/3	
Gado								50 100 100					50 100 100
Schalker				2 5 30	0 0 17	5 46 46		0 0 14	0 9 13	0 26 43	7 39 75	2 14 26	2 16 33
Thermopane	0 0 0	0 0 25	0 33 67	8 12 24	0 25 63	0 3 32	3 16 36	1 14 53	2 11 35	1 3 12	1 5 19	0 25 55	2 11 34
Aluco												0 100 100	0 100 100
Aterphone									30 60 60			0 100 100	27 64 64
Cudo									10 50 90	3 33 97	0 30 74	0 0 60	3 30 85
Duoterm										0 0 100	0 46 92		0 38 94
Multipane										100 100 100	0 100 100	60 80 100	88 96 100
Polyglass					50 100 100		10 90 100	64 93 100	2 22 87	0 18 68	0 0 31	0 7 21	8 29 67
Polyverbel						56 67 100	61 81 99	18 48 58	2 17 39	0 36 76	0 7 11		33 53 73

Also for Schalker and Thermopane, the production from some of the years seems to be much better than from some of the others. In general, the results may look discouraging. It should be noted, however, that about two third of the Schalker and Thermopane units were still in good condition after a service period from 20 to 32 years.

The measured dew points have been treated statistically. The limited space available does not make it possible to present all data here, but a few selected results can be given. Figure 2 shows the median dew point values for the Thermopane units, as measured in 1963, 1973 and 1983 respectively. All units with a dew point at or above the critical limit of -5 °C are here for simplicity marked with a dew point of -5 °C. There is, as can be expected, a move towards inferior dew point with increasing age. For the years 1953, 1955, 1958 and 1962/63, the average unit had in 1983 reached the critical limit. This corresponds very well with the figures in Table 1. The average remaining service life for the rest of the units can be predicted from the data given.

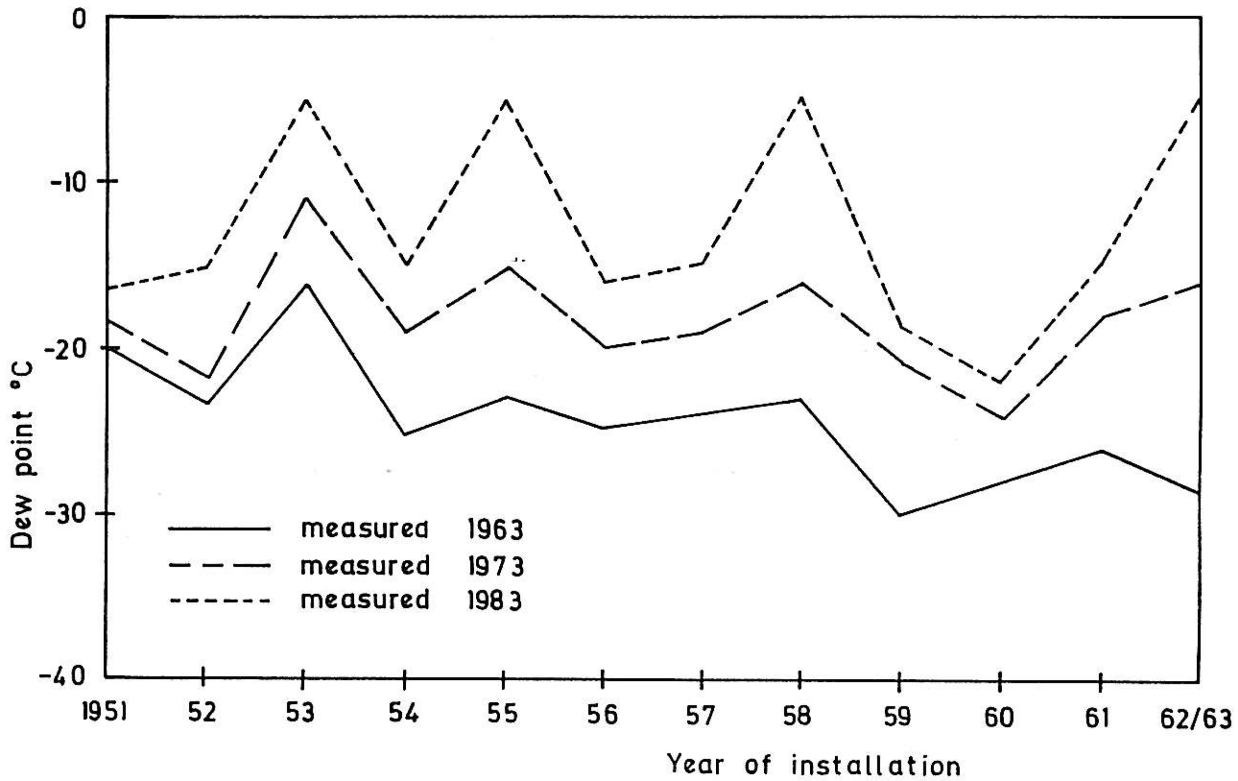

Fig. 2. Median dew points for the Thermopane units

Another selected set of results is given in Table 4, showing the damage frequencies as a function of the type of window. More data will be given in the final report.

It should be emphasized that the results presented here are valid only for the types of sealed glazing units produced in the years from 1951 to 1963, installed in the windows from that period of time with the installation technique and materials used in the same period.

Table 4

Distribution of recorded damage on different kinds of window, all types of units included

Kind of window	Number of units checked	Damage frequencies, %		
		1963	1973	1983
Fixed windows	1027	10	30	55
Horizontally pivoted windows	515	11	30	54
Sidehung windows	121	7	20	55
Top- and bottom-hung windows	79	19	48	83
Doors	27	11	33	56
Total	1769	11	31	56

References

1. Tore Gjelsvik: 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.