(CV MA) NEWS LETTER 16

British Technical Committee, Corpus Vitrearum Medii Aevi

Physics, University of York 8 September 1975 Ref. TC/75/7

CONTENTS

1 GENERAL

1.1 DANGERS TO PERSONNEL OF USING HYDROFLUORIC ACID

In item 1.3 of N.L. No.15 I drew attention to the dangers to health of using hydrofluoric acid and I am grateful to Mr Francis Stephens, ARCA for sending me some more information on the subject. He points out that full details of the complete aciding process, the equipment needed and the precautions to be taken are given on pp 83-87 of Patrick Reyntiens' book "The Technique of Stained Glass" (Batsford, London, 1970); this book contains much additional information on stained glass and is recommended to everyone who has not yet seen it.

Mr Stephens goes on to summarise his advice:

(a) Never add water to acid. Always add acid to water otherwise explosions might occur.

(b) All aciding, even on a small scale, should be carried out well away from all other glass. If possible, it should be carried out in a separate room. Always neutralise any acid (for example with chalk or limestone chippings) before putting it down a drain.

(c) Keep all acid bottles (even with screw tops) well away from any glass. The fumes will attack all nearby glass, including the operator's spectacles.

(d) He regards gloves as being a possible danger because they may develop pin-holes. Instead he recommends rolling up the sleeves and constantly dipping the hands in a large bath of water.

(e) Ensure that the doctor, whose name and telephone number are displayed at the work-place, is conversant with the dangers of hydrofluoric acid.

He also comments that many stained glass artists have sustained burns of a minor nature at some time or another but it seems that the only death that could be partly attributable to hydrofluoric acid was that of Harry Clarke, the Dublin Artist (1889-1931) whose tuberculosis may have been accelerated by the vast amount of aciding which he undertook on his finely-detailed and intricately-worked windows.

1.2 DOES FUNGUS GROW ON MEDIEVAL GLASS?

Suggestions are made from time to time that fungi can grow on medieval glass. There is then the question "What do they eat?". Mosses, lichens, liverworts and algae can certainly grow on medieval glass because they are green plants and contain chlorophyll. Thus they can make their own food from carbon dioxide, water and sunlight, and they do not need a separate source of food; for example, rotting wood is a favourite food for fungi although some specialised fungi can exist on sulphur or iron.

One well-known stained glass restorer recently sent me the photograph, reproduced as Fig.1, from Barsham Church. The plating glass was broken by a stone and a white stranded deposit formed inside the space. It certainly resembles a fungus and the restorer kindly sent me a piece of the glass with some of the white material on it.

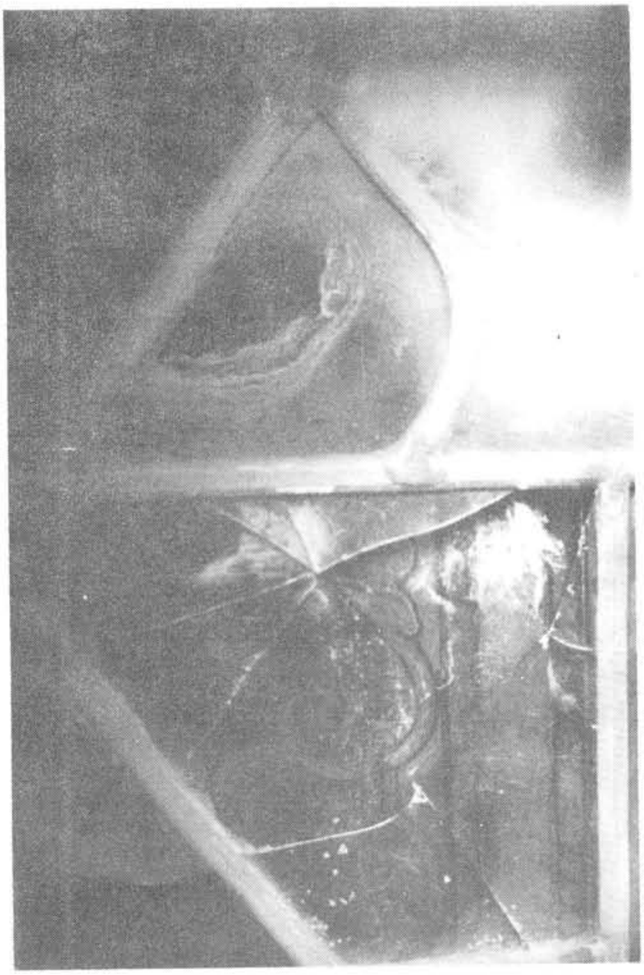


Fig. 1 This window at Barsham Church has a white stranded deposit between the stained glass and the outer protective glazing. The deposit looked remarkably like a fungus but the white deposit on one of the pieces of outer glazing proved not to be a fungus; it was either gypsum or silica.

If anyone thinks they have evidence of a fungus growing on medieval glass, and without any obvious source of food such as rotting wood, will they please send me as much of the material as possible.

Examination under a microscope failed to show any fungal hyphae (the thread-like body-cells of the fungus) and some "chemical" tests were therefore carried out with the kind assistance of Dr R.E. Hester of the University of York. It may be of interest to readers to know what simple "chemical" tests were carried out, so that if they think they have found some fungus they may get some of the tests done.

Glass tubing was drawn out to form fine nozzles so that minute drops of liquid could be put on the glass while it was being watched under a low-power microscope in order to observe any change in the white material in the presence of the drop of liquid. The liquids were:-

(a) distilled water: no change observed. Hence the material was not soluble in water (eg, not sodium carbonate, sodium sulphate, etc).

(b) dilute hydrochloric acid (2M): no change observed. Hence the material was not a carbonate or a sulphite (eg, not calcium carbonate).

(c) concentrated sulphuric acid (18M): no real change observed; some minute bubbles appeared but the white material remained apparently unaltered. No charring occurred and hence there was no organic material present (ie, no fungus). This was confirmed by pushing some fibres from torn paper into the drop; they turned brown and then disintegrated. (We believe that the minute bubbles represented air trapped between the particles as the acid spread quickly over them.)

(d) dilute sodium hydroxide (2M): no change observed. Hence the material was not an ammonium compound from polluted air (eg, ammonium sulphate). In carrying out this test it should be noted that "old" sodium hydroxide solution may have absorbed carbon dioxide from the air and it could then form bubbles with the acid.

(e) flame test. A "flame test" was carried out using hydrochloric acid on a piece of platinum wire. No satisfactory evidence of the brick-red calcium flame was seen although by that time we were running short of material. Hence the white material probably was NOT gypsum (calcium sulphate) and it may have been silica.

Thus we were not able to identify it positively but it certainly was not a fungus. It seems to be silica (or perhaps gypsum) which took a form resembling that of a fungus. It should be remarked that gypsum is a surprisingly inert material and it was not easy to produce the red flame colour, even with a sample known to be gypsum.

Does anyone have any positive evidence of fungus on medieval glass?

1.3 REVERSIBILITY OF AN EPOXY RESIN

In item 1.6 of N.L. No.15 I reported the success which Mr Frederick Cole had had at Canterbury in removing Araldite AY 103, which had been hardened with HY 951, by using green-label "Nitromors", and I announced that he would be extending the experiment to 12th c. glass with defective paintwork.

Fig.2 shows an enlarged view of the piece of glass (x 4.5) when the defective paintwork had been touched-up with coloured Araldite as far as the vertical black line. The loose and flaking paint had thus been stabilised and the restoration had filled-in the missing colour.

After curing for 24h at 70°C, and allowing to cool, the glass was treated for 10 minutes with green-label "Nitromors". The coloured epoxy was then easily wiped away to leave the paint as in Fig.3. Very little of the original paint was removed during removal of the epoxy resin but any which was lost would probably have disappeared anyway in the course of time if the paint had not been stabilised.

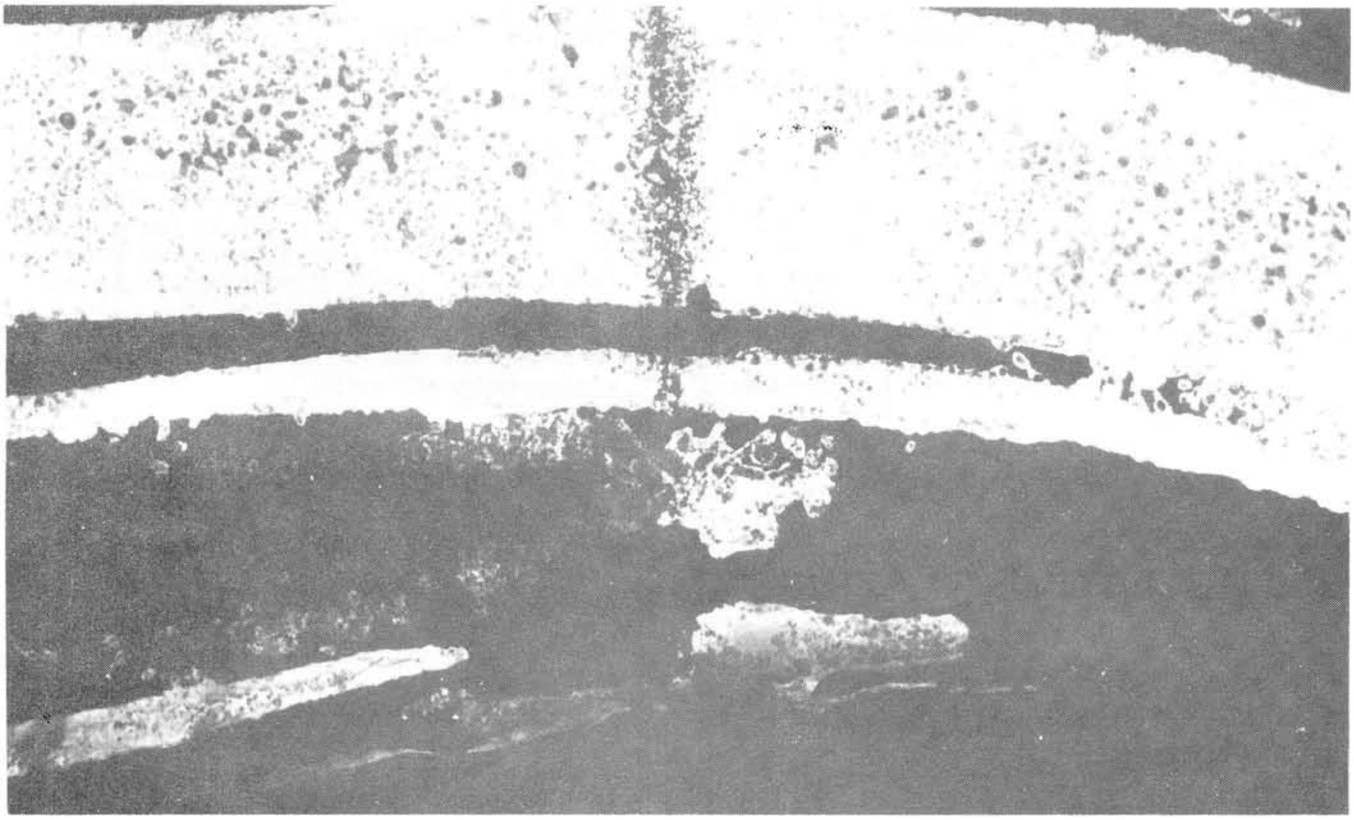


Fig. 2 This is an enlarged (×4.5) view of some defective paintwork on a piece of 12th century glass from Canterbury Cathedral. That part on the left, as far as the black vertical pencil line drawn on the glass, has been touched up with Coloured Araldite AY103, hardened with HY951, and cured for 24 hours at 70°C as carried out during restoration work at the Canterbury Glass Restoration Studio. Compare Fig. 3.

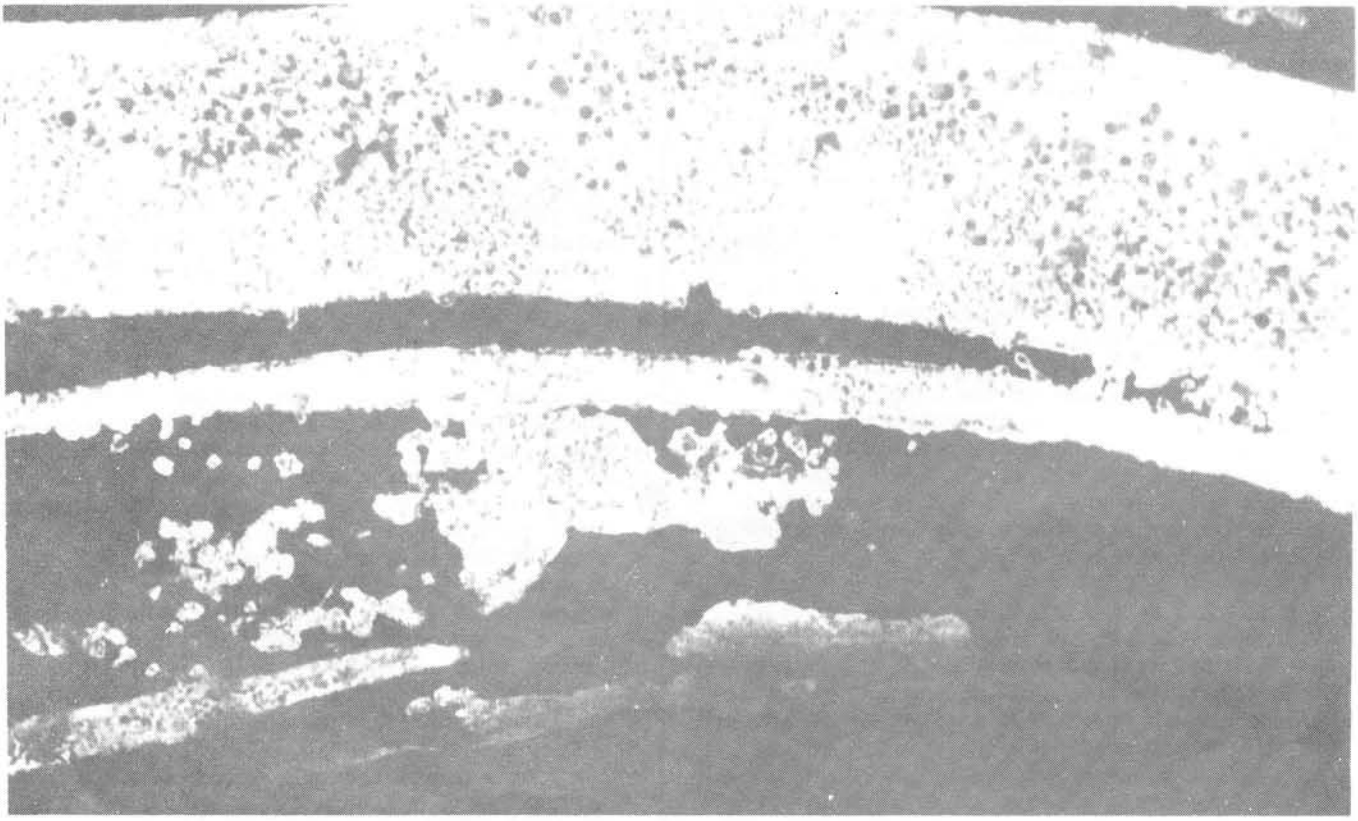


Fig. 3 This is the same piece of glass shown in Fig. 2 but the cured Araldite has been treated with Green Label Nitromors for 10 minutes and then wiped clean. It can be seen that all the Araldite has been removed without noticeably altering the paint, thus showing that this restoration technique is reversible.

1.4 WAS TOO MUCH BORAX ADDED TO SOME OF THE PAINT USED BY WILLIAM MORRIS?

Mr Martin Harrison, Honorary Curator of the Ely Cathedral Stained Glass Museum, has written to me about the way that some stained glass in the 1870's has lost its paint. William Morris wrote to his friend and patron, the Earl of Carlisle, in 1881 stating that he and many other glass-painters "were beguiled by an untrustworthy colour, having borax in it some y ears ago; and the windows painted with this are going all over the country .... Borax is the name of the culprit: the colour-makers, finding that glass-painters wanted a colour that would burn at a lowish temperature, mixed borax with it to that end; but unluckily glass of borax is soluble in water and hence the tears wept by our windows - and our purses".

There is no doubt that too much borax would render the paint soluble in water. Also, if the word "mixed" is correct, the mere mixing of borax with the paint (instead of sintering them together) would give a soluble paint.

Does anyone know anything more about this problem? How much borax was added? How many windows were affected?

2 PROTECTIVE GLAZINGS

2.1 RESULTS FROM THE EXTERNALLY-VENTILATED WINDOW AT YORK MINSTER

2.1.1 Introduction

This experiment arose directly from the isothermal experiment at Sheffield, which has already been reported in item 2.1 of N.L. No.15. Through the far-sightedness of the Department of the Environment, which paid for the entire experiment, all the equipment was moved from Sheffield to York so that this supplementary study could be carried out. By the kind permission of the Dean and Chapter of York Minster all the thermocouples and other sensors were installed on window No.17 (window sVIII) of the Minster, i.e. the second window from the west in the South Choir Aisle. This window was chosen because it already had an external protective glazing and the outside could easily be reached from the flat roof of the Vestry with the aid of simple scaffolding.

The external glazing, in the form of leaded diamond quarries, lies some 53 to 65 mm behind the fifteenth century window, the gap being 65 mm at the glazing grooves and 53 mm in the centre. For purposes of the experiment, adjustable sliding shutters were introduced at the top and bottom of the outer window so that an adjustable flow of ventilation air could take place through the bottom slot, up the interspace and out at the top. The maximum width of the slots was 150 mm and at the end of the experiment they were completely sealed and pointed.

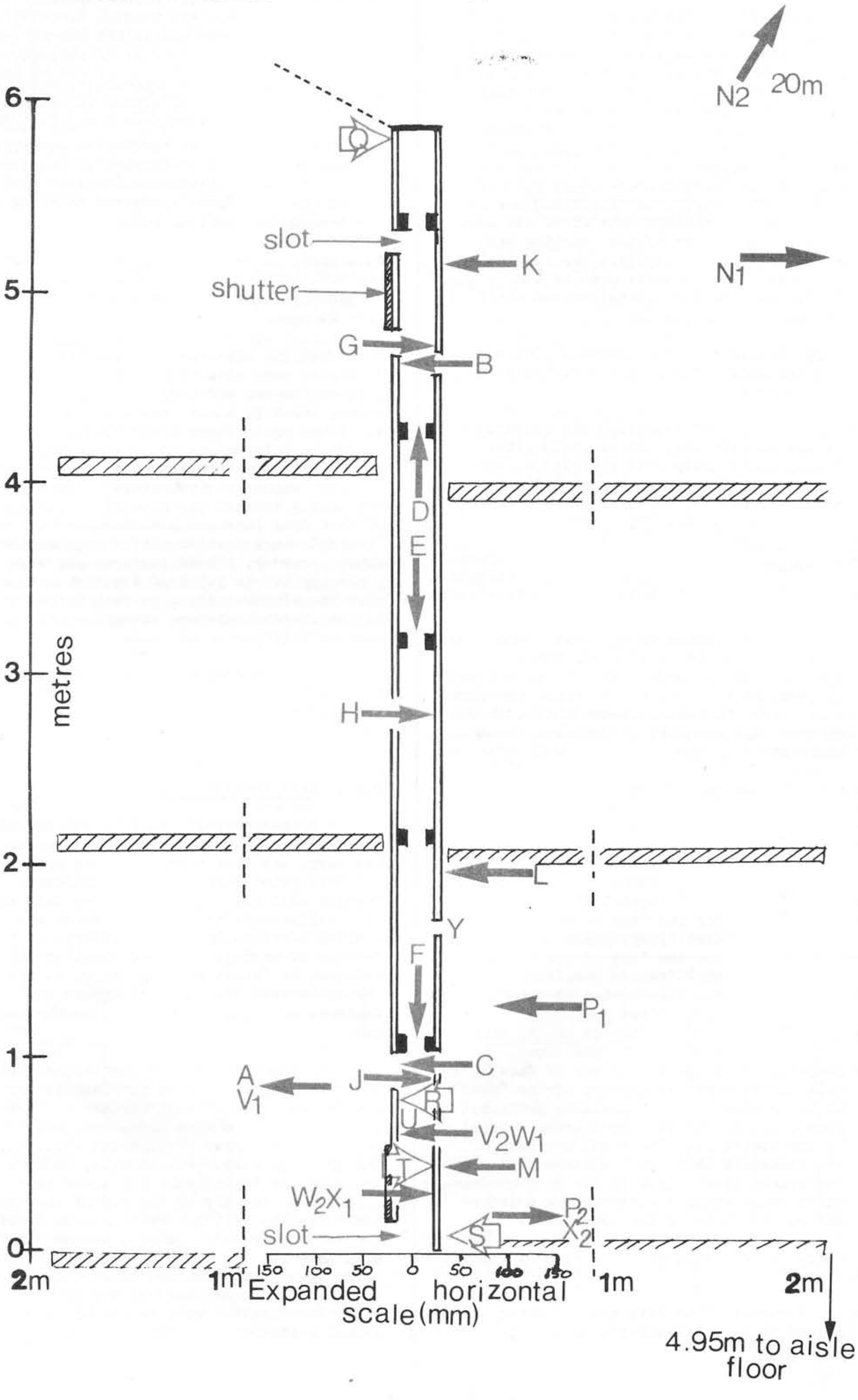
It will be useful to emphasise the difference between this experiment at York and the one previously carried out at Sheffield. At Sheffield the ventilation air in the interspace had been drawn from <u>inside</u> the building; it generally passed <u>down</u> the interspace and its initial temperature was higher than that of the "medieval" glass. At York, the ventilation air was drawn from <u>outside</u> the building; it generally passed <u>up</u> the interspace and its initial temperature was lower than that of the modern external glass.

There is thus a fundamental difference in approach between the two experiments, although both are designed to reduce the effects of condensation on the medieval glass. Here it must be remembered that the air drawn from inside a building usually contains more water, and sometimes much more water, than air drawn from outside the building. This may still be true even when rain is falling outside and the reason is that the outside air is generally colder than the inside air so that it has a much lower capacity for holding water vapour. For example, during the winter the air temperature may be 5°C and, even when it is raining (relative humidity = 100%) the water content of the air will be 6.8 g/m^3. By comparison, the temperature of the air inside the building might be 18°C, and the relative humidity 65%; the water content of the air would then be 10.3 g/m^3, and its dew point would be 11.5°C. Thus the water content of the inside air would be 50% greater and the dew point 6.5°C higher. At 0°C and 100% relative humidity the water content would be 4.83 g/m^3 or less than half that of the air inside the building.

With the "isothermal" window at Sheffield the intention would be to reduce the chance of condensation at night by keeping the medieval window within 1 or 2 degC of the temperature of the air inside the building. With the ventilated window at York the intention would be to reduce the chance of condensation at night by keeping the medieval glass some 2 - 3 degC warmer than it would have been without any external protection. If any condensation does occur during the night it would dry out during the following day when the space warms up and there is an increase in the flow of ventilation air through the cavity.

There is another experimental difference between the two studies; at Sheffield the width of the space between the two glazings was altered but at York the space was fixed and the amount of ventilation was changed by altering the adjustable slots.

FIG 4 SIDE ELEVATION OF THE WINDOW



2.1.2 Experimental details

The details of the Sheffield experiment were given in Figs. 1 and 2 of N.L. No.13. At York Minster the experimental arrangement is given here in Fig.4. It is closely similar to the arrangement at Sheffield except that the incipient condensation gauges were re-positioned as shown at QRS and T. Another important difference arose from problems in measuring air temperatures when the sun was shining and the thermocouples could receive radiant thermal energy. At Sheffield the PVC insulation on the thermocouple wires had sometimes been within 1 mm of the junction and there was the possibility that the insulation would get warm and transfer heat to the junction; at York the insulation was stripped back 50 mm from the junctions.

The locations of the thermocouples are shown diagrammatically in Fig.4 according to the following key.

A = thermocouple for measuring the temperature of the outside air; it was held with string 160 mm away from the window, and attached to thermopile V_1, used for the same purpose.
B = thermocouple at the top of face 2.
C = " " " bottom of face 2.
D = " " " top of the interspace.
E = " " " middle of the interspace.
F = " " " bottom of the interspace.

Note, the wires leading to D, E and F were fastened to small blocks of wood, forced between the T-bars, shown as black squares on the diagram, so that the thermocouple junctions would be likely to remain in the middle of the interspace; all remained in position during the experiment.

G = thermocouple at the top of face 3.
H = " " " middle of face 3.
J = " " " bottom of face 3.
K = " " " top of face 4.
L = " " " middle of face 4. (about 1m lower than H)
M = " " " bottom of face 4.
N_1= " for the "top of the Minster air" (first position)
N_2= " for the "top of the Minster air" (second position)
P_1= " for the "bottom of the Minster air" (first position)
P_2= " for the "bottom of the Minster air" (second position)
Q = condensation gauge at the top of face 1. This was attached at the top of the "head" of the window where it would be protected from ordinary rainfall (not driving rain) by the stonework. The total overhang of the stonework is shown diagrammatically by the broken line. This is the only condensation gauge which registered any moisture during the whole of the experiment.

R = condensation gauge at the bottom of face 2.
S = " " " " " " " face 4.
T = " " " " " " " face 3.
U = an electronic "humidity sensor" which proved to be quite unsatisfactory.

V_1= outer end) of the thermopile measuring
V_2= inner ") the difference between face 2 and the outside air. V_1 and A were maintained 160 mm from face 2 by guide strings.

W_1= face 2 end) of the thermopile measuring
W_2= " 3 ") the difference in temperature between face 2 and face 3.

X_1= face 3 end) of the thermopile measuring
X_2= inner ") the difference in temperature between the "Minster air" and face 3. P_2 was attached to X_2.
Y = anemometer sampling hole.

Note that, in the diagram, the inner part of the horizontal scale (0-200 mm) has been expanded 5 times compared with the outer part (1 - 2m).

When the experiment started on 6th March, N_1 and P_1 were attached to the inside scaffolding, at the top and near the bottom. On 24th March, however, a new thermocouple 20m long was taken up to the clerestory level in order to obtain information about temperatures there; in operation, however, the recorder readings showed a distinct tendency to "hunt", presumably because the electrical resistance of this long thermocouple disturbed the "homing" characteristics of the potentiometric chart recorder. These temperatures were generally 1.0 to 1.5 degC lower than those near the window. Also, on 24th March, the bottom thermocouple was attached to X_2 and re-labelled P_2.

The thermocouple readings were found to be reproducible to ± 0.25 degC and those of the thermopiles to ± 0.1 degC.

2.1.3 Experimental Results

A 25-page report was prepared for the Department of the Environment, who sponsored the work, and they have now given permission for this brief summary to be published. Readers will see that it provides data about externally-ventilated windows which were not available before and puts this type of protection of medieval stained glass in the same category as "isothermal" glazing, so that the choice between the two will depend on such features as cost, convenience, aesthetics, etc.

The experiments were carried out between 6th March and mid May 1975. Thus no very cold weather was encountered, nor any which was very humid with a high dew-point, but some hot sunny days were encountered which warmed the glass greatly. For example, on 23rd April at 12.30 the top of face 2 reached 46.5°C (116°F) and the air at the top of the interspace reached 37.5°C. Nevertheless despite the absence of cold weather, enough basic data have been obtained to enable predictions to be made (from standard meteorological data for the place concerned) of the frequency with which condensation will be encountered during winter weather.

The data on the charts was handled as described in section 2.1.1 of N.L. No.15, five sheets of "transparent" graph paper being prepared for each 25-hour experiment. The widths of the ventilation slots were changed 12 times, at intervals of about 4 days. At the end of each such 4-day interval a 25-hour period was chosen which was, if possible, free from sunshine because the strong heating effect of any sunshine completely altered the behaviour of the window. The charts for sunny days were also examined in order to discover the highest temperatures reached at any point.

2.1.4 The daily fluctuation in temperature

On days which were not sunny there was a fairly characteristic pattern of temperature change on the window, the readings being highest in the mid-afternoon and falling steadily during the night until they were coldest just before dawn. The temperatures started to increase about half an hour before dawn and rose by about 3 degC by mid afternoon.

In general there was only a slight variation in temperature over any one glazing, the top of a window often being about 0.5 degC higher than the bottom (note also item 2.2.4 for observations by thermography) at night or when there was no sunshine but it was interesting to find that there was an appreciable gradient up the interspace between the two glazings (sometimes as much as 2 degC even during the night) when the ventilation slots were open. This resulted from the horizontal temperature difference across the interspace (face 3 being 1.5 to 2.5 degC warmer than face 2 during the night); thus the ventilation air entering the bottom slot started by being slightly colder than face 2, but it gained heat from the warmer face 3 as it passed upwards so that, at the top of the window, it was nearly as warm as face 3. When the sun was shining the gradient was much higher, eg more than 10 degC but readings are not quoted here because the shadow thrown by the outside scaffolding may have distorted the picture and because it is quite difficult to measure air temperatures accurately when the sun is shining. On some days the bottom of the window was warmer than the top and this condition was found on the day when the thermography was carried out, see section 2.2.4.

2.1.5 The effect of altering the width of the ventilation slots

In N.L. No.15 the results from the isothermal experiment were quoted in such a way that the temperature drop (Y) from the inside of the building to face 3 can be compared with the total temperature drop (X) from the inside of the building to the outside air. We want to keep Y as small as possible so that condensation does not occur on face 3.

The same procedure has been used in Table I for periods during the night. The results are listed for six different widths of ventilation gaps and the ratios of Y/X are also given so that the value of Y can be calculated for any given value of X. (These ratios may differ slightly from averages calculated from the figures in Table I because they are derived from a much larger number of results.)

It will be seen from Table I that, when the slots are more than about 10 mm wide, the ratio of Y/X does not differ greatly from a value which is somewhat more than 0.35 but when the slots are reduced to less than 10 mm the ratio of Y/X decreases to a minimum which is less than 0.25, when the slots are fully closed. Thus face 3 is kept warmest (the ratio of Y/X is smallest and the temperature drop is lowest) when the slots are so narrow that they would be difficult to construct, and even to keep clean.

TABLE I CHANGES IN TEMPERATURE DIFFERENCES (degC) AS THE VENTILATION SLOT IS CHANGED

Date	10-11 April		10-11 Mar		12-13 Mar		16-17 Mar		25-26 Mar		1-2 May	
Width of slot (mm)	150		65		25		10		5		0	
Time	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
18.00	8.8	3.5	7.5	3.2	7.4	3.0	8.4	2.5	5.8	1.8	*	*
21.00	8.6	3.8	8.0	3.4	6.5	2.3	7.7	2.5	6.8	2.1	4.8	1.6
24.00	6.9	3.0	6.9	2.9	7.5	3.0	7.2	2.3	8.1	2.8	5.1	1.5
03.00	6.0	2.5	7.1	2.8	7.2	2.9	7.7	2.7	7.9	2.5	5.7	1.6
06.00	5.6	2.3	7.3	3.0	6.7	2.7	7.8	2.8	8.6	2.7	5.4	1.4
Y/X	0.415		0.412		0.384		0.332		0.313		0.228	

* = sun was shining
Y = temperature drop (in degC) from inside the Minster to face 3
X = total temperature drop (in degC) " " " to the outside air

TABLE II AIR VELOCITIES IN THE INTERSPACE

Width of slots (mm)	Air flows encountered		
	Position	Direction	Velocities (m/s)
65	near face 2 mid interspace near face 3 near face 4	upwards " " downwards	0.5 - 0.7 0.75 - 1.0 0.2 - 0.35 0.05 - 0.15
10	mid interspace	upwards	0.6 - 0.8
5	face 2 (no sun) " " (sunshine) mid interspace near face 3	" " " downwards	0.1 - 0.2 * 0.2 - 0.3 0.2 - 0.5 0.05 - 0.2 *
0	near face 2 near face 3	upwards "	0.02 - 0.03 0.05 - 0.15

* When smoke was introduced at the bottom slot it travelled up the window for about 2 metres and then came out at the bottom again, but at a different point.

Thus it seems that the smallest slot should be used which can be constructed in practice by architects and glaziers! The air movement which occurs during the day with the narrowest of slots (and even with none at all! - see item 2.2 of N.L. No.15) will be sufficient to dry out any condensation which might occur during the night.

2.1.6 Air flows in the interspace

When the ventilation slots were fairly well open, there were strong air-flows up the interspace as measured with the vibrating hot-wire anemometer but with narrow slots the flow was reduced and there was some re-circulation. The examples given in Table II show the magnitude of the flows encountered.

2.2 THERMOGRAPHIC STUDY OF WINDOWS IN YORK MINSTER

2.2.1 Introduction

Thermography is a method of measuring temperatures at a distance from the object being investigated, using a special television-type camera which is sensitive only to the "dark" radiation from the "warm" object. When a filter is used which transmits only radiation between 3.1 and 5.5 μm the glass appears quite opaque and the resultant "picture" shows the temperature variations over the inside of the glass, and of the surrounding walls, either as patches of dark (colder) or bright (warmer) light or (in another version) as areas of different colours which represent different temperature isotherms (regions of equal temperature).

Thus thermography is an important supplement to the work with thermocouples described in Section 2.1. The thermocouples measured temperatures on face 4 at three points only (K, L and M in Fig.4) but the thermograms measure face 4 temperatures at many thousands of points simultaneously (at about 42,000 points on each thermogram every 1/16th second).

Thanks to the generosity of the Department of the Environment and the kindness of the Dean and Chapter of York Minster, Dr L.M. Rogers, of the Unit Inspection Company, Sketty Hall, Swansea, SA2 8QE, was able to carry out a comprehensive thermographic study of many windows in York Minster, both with and without external protective glazing, on 19th and 20th June 1975, using an AGA 750 thermal imaging camera. The full results will be published as a joint paper with the Building Research Establishment. On 20th June the experiments started before dawn (at 03.30) so that the effect of daylight could be studied.

2.2.2 Measurements before dawn

Before daybreak the windows were colder than the walls of the cathedral and they showed up as dark areas (temp. 13.6 to 14.1°C) against the bright walls which had a temperature of 16.6°C (see Fig.5). Windows which had external protection were somewhat warmer, at 15.3°C; thus external protective glazing raised the temperature of face 4 by 1.5°C before dawn. The patterns of the stained glass windows did not appear in the thermograms because all the medieval glass in any one window was at the same temperature, whether it was coloured or not, but the saddle bars of the windows could be seen as warmer lines at night, and any plated heads showed up by being about 1 degC warmer than the rest of the window, which had a constant temperature within ± 0.25 degC.

At about 06.00 the temperature of the glass in a north facing window (No.2) was the same as that of the wall (16.6°C) and the two were then indistinguishable on the thermogram.

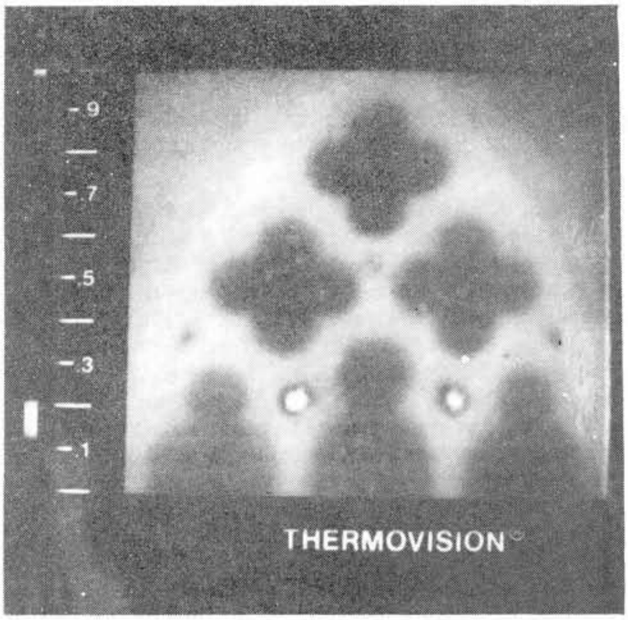


Fig. 5 This shows the 'Thermal image' of the tracery panels of window No. 28 in the south aisle of the Nave of York Minster at 03.56 on 20th June, about an hour before sunrise. The date of the glass is early 14th century. The stonework, with a temperature of 16.6°C, appears bright because it is 1.3°C warmer than the windows which have been cooled to 15.3°C by the cold night air. The stained glass, including these tracery panels, has an external protective glazing but the 'eyelets' in the tracery are not protected and the temperature of the glass is 14.3°C, or 1.0°C colder than the protected stained glass.

The isotherm (0.5°C wide) at 0.15 on the scale at the left (=14.3°C) has been 'picked out' to give a bright image at the eyelets and thus determine their temperature with an accuracy of ± 0.25°C. The temperature of the protected stained glass was constant, within ± 0.25°C over the entire window.

2.2.3 Window No.40

From 06.00 onwards the windows steadily became warmer than the walls and, at 09.25, an unexpected pattern could be observed in the bottom panel of the central light of the north-facing window No.40. This panel contains a few medieval quarries and many 19th century quarries of both painted and clear glass; it does not have external protective glazing. These 19th.c clear-glass replacement-quarries appear dark in the thermogram (temperature = 16.5-17.0°C) because they have failed to absorb much thermal energy from the sky. In contrast the four clear-glass medieval quarries could easily be identified because they appear brighter in the thermogram (temp. = 18.5-19.0°C); they have absorbed more thermal energy (presumably because they contain iron and manganese, perhaps even as much as 1% each of Fe_2O_3 and MnO_2 as in the reference medieval glass sample No.44 from Evreux Cathedral). All the coloured medieval glass appears to be at the same temperature as the clear medieval glass and none of the design appears in the thermogram; the inside air temperature at the time was 16.5°C.

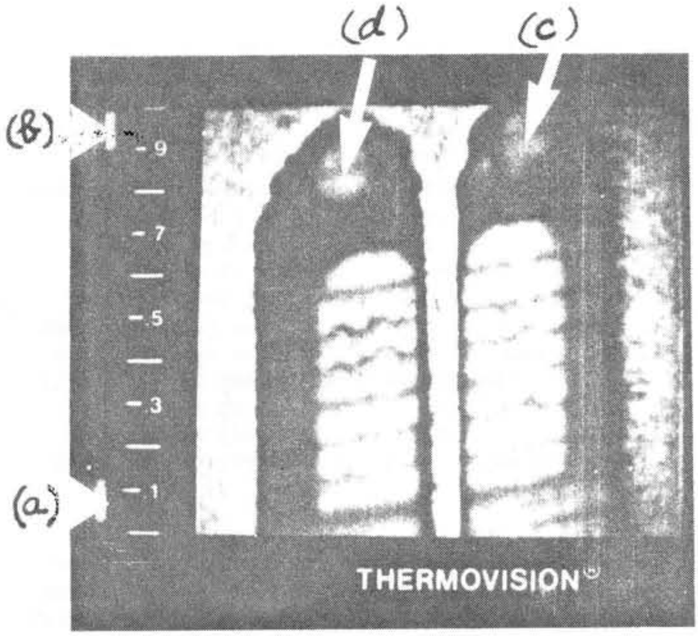


Fig. 6 This shows the 'Thermovision image' of window No. 11 at 09.50 on 20th June when there was a brief burst of sunshine falling on it. Two widely separated isotherms have been used in producing the image, as indicated on the scale at the left. Isotherm (a) is at 17.0°C and it is responsible for the brightness of the image of the wall on the left of the picture. Isotherm (b) is at 21.5°C and is responsible for the brightness of the two 16th century stained glass panels with rounded tops which have been inserted in the lancets; both have an external protective glazing.

There are two roundels of 19th century stained glass (c) and (d) in the heads of the lancets which appear bright in the thermogram because they absorb the thermal energy in the sunlight.

The surround of clear modern diamond quarries is colder than the stained glass because it has a low iron content and does not absorb thermal energy well. Its temperature (19°C) is intermediate between those of the walls and of the stained glass; this isotherm was *not* selected for display and hence the surround appears dark in the thermogram.

The six saddle bars in each panel can be clearly seen as 'cold' lines. In the left-hand panel two of the saddle bars are curved in order to avoid the various small heads in the design. There is no evidence of the coloured design in the 16th century glass because all medieval glass (whether coloured or clear) seems to absorb all the thermal energy available in sunlight.

2.2.4 Effect of sunshine

At 09.50 there was a short burst of sunshine (the only sunshine during the day) and the effect was monitored in the south-facing window No.11, as shown in Fig.6. The inside air temperature was 17.0°C and the clear-glass background to the panels appeared dark (19°C) but the 16th century glass with external protection was warmer (21.5°C) and the saddle bars were colder (18.5°C). (See also below regarding the effect of sunshine at St David's Church, Swansea.)

At noon the apparatus was moved to the scaffolding on window No.17 (used for the experiment reported in Section 2.1). The inside air temperature here was 18.0°C and the temperature of the 15th century glass was 23.0°C except for a horizontal band in the lowest panel which was 1°C lower; it was then noticed that this part of the panel had bulged inwards (towards the camera). No differences were found in the temperatures of any parts of the medieval glass, whether it was clear white or dark blue (showing that all the radiant energy from the daylight was being absorbed by medieval glass of any kind) and all the lead lines showed up quite clearly as "cold" lines (20.0°C) but it is not clear why they should be 3°C colder than the glass.

At night there was no detectable difference in temperature over face 4 on any window (except for plated heads and saddle-bars which were warmer than the glass) but during the day the tops of the windows (whether protected or not) were 0.5°C colder than the bottoms. During the day the plated heads were warmer than the rest of the glass and the saddle-bars were colder than the remainder of the window; the coldest part of these thermograms was the stone floor of the nave. Thermography on the outside of the south facing window No.29, at 18.58 on 19th June when there was no sunshine, gave a glass temperature of 18.3°C with an inside air temperature of 17.0°C and an outside air temperature of 18.0°C.

2.2.5 Experiment in Swansea on the effect of sunshine

A supplementary experiment was kindly carried out by Dr Rogers on 17th July at St David's Church Swansea, by kind permission of Father Peter and Father Stephen. There was continuous bright sunshine and the resolving power of the thermograms was so great that they could detect the cool shadow thrown by the wire-mesh guard on the outside of the window. In the strong sunshine the stained glass warmed up by 15 to 19 degC compared with an outside air temperature of 22°C, but clear modern glass in the adjacent lancet warmed up by only 7 to 11 degC. Other glass, described as "very bubbly but uncoloured" warmed up by 13 to 15 degC above the outside air but the date of this glass is not known although it appears modern from the photographs. The leading was again colder than the glass, being 8 to 12 degC above the outside air. As far as the stained glass is concerned, there is no evidence of its coloured pattern in the thermogram (although its design can easily be seen from the colder lead lines which are quite distinct) and it is concluded that all stained glass, and all medieval glass (whether coloured or not), warms up to the same extent in sunshine.

3 TESTS OF WAR-TIME STORAGE ARRANGEMENTS

3.1 INTRODUCTION

In item 1.4 of N.L. No.12 I included a note that the Central Council for the Care of Churches had, in 1940, recommended that panels of glass should, for war-time protection, be "tightly packed .... with dry sawdust between each panel". I also stated that an experiment would be carried out at the York Glaziers Trust, with the help of the Special Grant from the Pilgrim Trust, in order to examine the consequences of storing such an assembly in a damp place.

A piece of British Simulated Medieval Glass No.2, 90 x 60 mm, with an excellent fire-finished surface, was air-abraded with No.3 grit over one third of its area and then cut into three pieces so that the air-braded part was equally represented on each piece. One of these pieces was kept as a control and the other two pieces were framed in leads and packed in dry English Oak sawdust in a wooden box.

3.2 PRELIMINARY OBSERVATIONS AFTER SIX MONTHS

The box was placed in a chamber in one of the corner bastions of the York City Wall (known locally as the "Deanery Dugout") for a period of six months. This chamber is very damp, even though it was one of the places used during the War for storing Minster glass; thus the box and the sawdust were quite moist when it was opened in July. The lead had many white patches on it and the shiny surface of the glass had become dulled; there were about 50 - 100 very small pits per sq.cm, which could easily be seen in reflected light and which could be "felt" with the finger nail. The abraded surface, however, had a similar number of duller points on the surface but they were not easy to see and could not be felt with the finger nail.

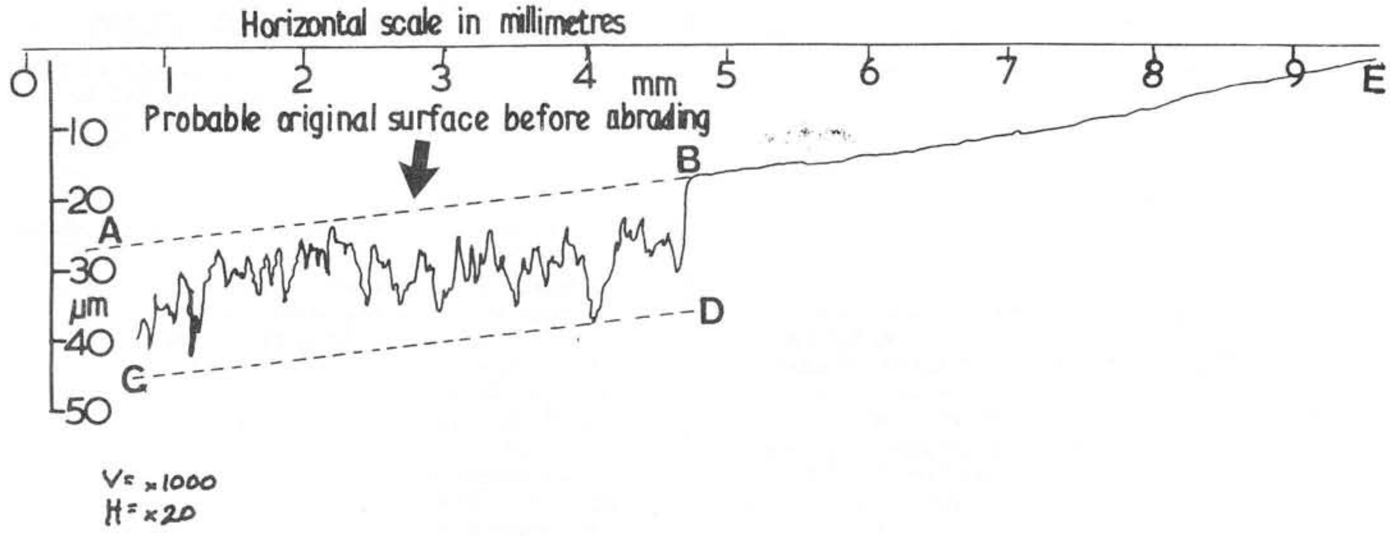


Fig. 7 NOT STORED IN SAWDUST

This is a Talysurf record of the two surfaces (airabraded on the left and fire-finished on the right) of the control sample, which had not been stored in sawdust. The abraded surface has an overall roughness of 18 micrometres and the fire-finished surface is smoother than 1 micrometre.

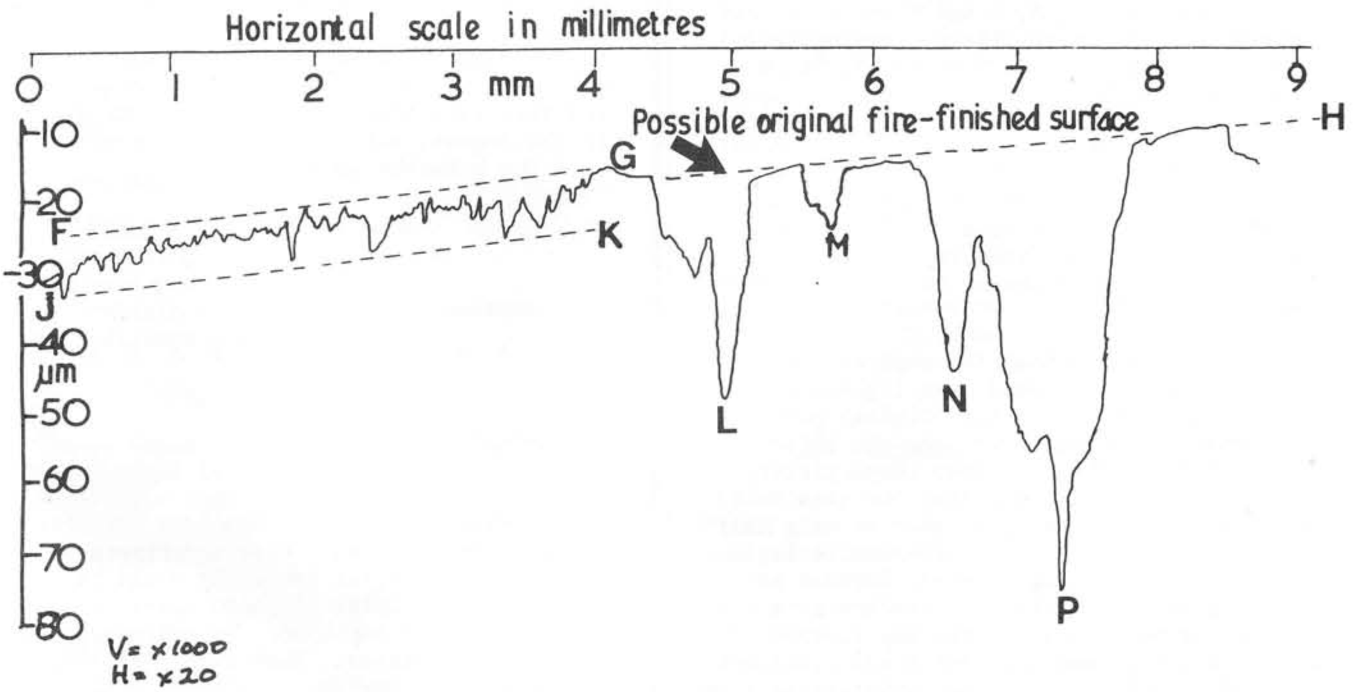


Fig. 8 AFTER SIX MONTHS IN SAWDUST

This is a Talysurf record of the same two surfaces on a sample of No. 2 glass which was stored in damp sawdust for six months. The original fire-finished surface has pits in the surface 0.5 to 1.5 mm wide and up to 63 micrometres deep, produced by the moist sawdust. The abraded surface on the left not only has no pits in the surface but also, for reasons which are not yet understood, has overall roughness which is only half that in the control sample.

Professor O.S. Heavens, at the University of York, kindly attempted to measure the depth of the pits by means of multiple interference patterns (Fizeau fringes) but there were two serious problems; the lack of optical flatness of the fire-finished surface and the steepness of the sides of the pits so that the fringes were very difficult to count.

3.3 TALYSURF MEASUREMENTS

Further physical examination of the surface was therefore carried out with the "Talysurf" at the Cutlery and Allied Trades Research Association in Sheffield. This sensitive instrument will greatly magnify surface irregularities, and produce a permanent record of these irregularities, as shown in Figs. 7 and 8. In this case the horizontal magnification was x20 (and the horizontal scales are marked in millimetres) and the vertical magnification was x1000 (so that the vertical scales are marked in micrometres).

Fig.7 shows the surface of the control sample (which had been kept in a cupboard at the York Glaziers Trust). Part of the abraded surface is shown between A and B, and part of the fire-finished surface is shown between B and E. The probable original fire-finished surface is shown by the broken line AB and it can be seen that the No.3 grit removed between 1 μm and 18 μm of glass, the deepest abrasions nearly reaching the line CD, and there were about 12 peaks to the millimetre.

Fig.8 shows the surface of the sample which had been stored in sawdust and the line GH probably indicates the original shiny fire-finished surface. Some of the pits which could be felt are L, M, N and P and it is not surprising that Fizeau fringe-counting failed to measure their considerable depth; L is 32 μm deep; M, 9; N, 31; and P 63 μm deep. This degree of attack in 6 months is surprising but what is even more surprising is the total lack of pitting on the abraded surface FG. It is also remarkable that the depth of the abrasions is much less than in Fig.7, the distance between the lines FG and JK being only 9 μm instead of the 18 μm in the control sample.

It is possible that the experimental sample had been airbraded more lightly than the control sample, but the original piece of glass had been air-abraded over one third of its surface and then cut into three pieces, so that it seems unlikely that one area would have been systematically abraded to only half the depth of the rest. An alternative explanation is that the damp sawdust, instead of producing pits, attacked the surface in a general way by dissolving the top surface away. Thus the explanation is not clear but the sawdust failed to produce substantial pits when the surface had been abraded!

The second experimental sample was replaced in the damp sawdust together with a similar-sized piece of 6mm polished plate glass (probably not more than 3 years old) and returned to the "Dugout" for another six months.

3.4 CONCLUSIONS

This important experiment, supported by the Pilgrim Trust special grant has led to three quite unexpected results:-

3.4.1 Wartime storage

It is clear that the advice given in 1940, to pack the glass in sawdust, could have had a damaging effect on medieval glass. It is true that we chose the worst conditions we could devise, using (a) English Oak sawdust which is the most acid of the common woods (pH = 3.3 to 3.9); (b) the glass was a rather "basic" one (ie, easily attacked by acids) of an Austrian composition, rather than an English composition; and (c) a deliberately damp location was chosen. Nevertheless, all three conditions might well have been encountered and obvious damage occurred in six months whereas the war lasted six years.

3.4.2 Effect of air-abrasion

It has been strongly argued (see, for example, items 1.2 and 187 (p.13) of N.L. No.15) that air-abrasion destroys the "protective skin" of the fire-finished surface. Yet here we find the shiny part being badly damaged and the abraded part not being damaged. Here, at least, better results were obtained by removing the "protective skin"!

3.4.3 An accelerated weathering test

This test has, quite unexpectedly, proved to be a useful accelerated weathering test in which well-marked damage occurs in 6 months! In fact, we are already proposing to exploit the results by asking Mr Cole to use his acid-polishing technique on a piece of No.2 glass and this will then be exposed in damp sawdust in the dugout, but it may not be necessary to wait for 6 months to elapse.

* * * * * * * * * * * *

NOTE: Will readers of these News Letters please draw my attention to any papers which should be abstracted here. It would be particularly helpful if photocopies of the papers could be supplied. My address is 5, Hardwick Crescent, Sheffield, S11 8WB, England.

Roy Newton

4 NEW ABSTRACTS

195. ENGLE, Anita (1973-1975) "Readings in Glass History" Nos 1-5. This is a series of volumes concerned with the history of glass and glassmaking, edited by Anita Engle and available from Phoenix Publications, POB 8190, Jerusalem, Israel. The first five volumes have the following among their contents and some of the individual articles will be abstracted in future News Letters.

196. GREEN, Maureen (1975) "New life for famous old stained glass in Canterbury Cathedral", Smithsonian, June 1975, 6 (3) 28-37.

This is a popularised account of some of the history of the Canterbury glass and the methods used for conserving it. There are excellent colour photographs of the glass in the Cathedral and of some of the conservation procedures in the restoration studio. The text ranges very widely, from theories about the origin of the genealogical windows to the reasons for the post-war deterioration of the glass. Details of the restoration procedures are discussed and the article is an interesting, if somewhat glamourised, account of all the problems and their solutions.

197. THOMAS, Brian (1975) "Stained glass: the craft that altered history", Creative Crafts Vol.1 pp 336-339, July 1975.

This is a somewhat provocative article in which the author claims that "Stained glass altered history by triggering off three revolutions at the same time: one was political, another architectural, and a third sociological". When there was no glazing, there could be no heat conservation and the great increase in glazing in the 12th and 13th centuries made it possible to have meetings of assemblies, with scribes to record their deliberations, during the winter; hence the political revolution.

Architecture is claimed to have been revolutionised because glass is cheaper than stone, so that the masonry could be reduced until it became the Gothic framework! The sociological revolution came by the way in which art forms were used to communicate ideas to the onlooker. Not everyone will accept his arguments but the article is undoubtedly stimulating. On p.338 he seems to suggest that 12th century glass was made by blowing a gather into a wooden box (Norman slabs) thus producing five pieces of glass per gather; the cylinder process, the crown process and the casting process are not even mentioned!

198. WALLS, Diana (1975) "Restoring Glass at York", Crafts, July/August 1975, pp.18-23.

This article is somewhat like No.196, being a popularised account of conservation and restoration of the glass of a major cathedral, this time York Minster. The content is necessarily somewhat different because it deals with the setting-up of the York Glaziers Trust by the Pilgrim Trust. It, also, has excellent illustrations and it gives a brief account of the way the art-historian can elucidate the real meaning of jumbled windows. Mention is also made of some of the scientific experiments being carried out inside the Minster or at the University of York.