Moisture investigations in connection with paints on external renderings
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PREFACE

European and Canadian practices in the usage of
exterior renderings, such as stucco, differ markedly.
Although they are widely used in Europe, in this country
they have only been popular in certain localities. Be-
cause there are some Canadian applications, the Division
of Building Research is interested in the properties of
renderings and the result of painting them.

Emulsion paints have been widely promoted on the
basis of their ability to "breathe" or transmit water
vapour. In Canada, their chief use has been on concrete
structures. However, in localities where stucco is used,
there may be a desire to apply emulsion paints for decora-
tive purposes. Concern has been expressed that their use
might lead to spalling of the rendering surface because of
repeated freezing and thawing cycles.

The work reported here shows that application of
emulsion paints to old rendering is satisfactory. If
applied to fresh rendering, damage from frost action may
occur if cement is not included in the formula. Emulsion
paints cannot be expected to waterproof masonry walls that
were improperly constructed in the first place.

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Ottawa   N.B. Hutcheon
September, 1969   Assistant Director

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MOISTURE INVESTIGATIONS IN CONNECTION
WITH PAINTS ON EXTERNAL RENDERINGS

1. Introduction and Literature Survey

Increasingly in recent years paints with a synthetic resin polymer base have been used as external coatings for rendering on buildings. These materials, under the generic name of "emulsion paints", are easily applied, cover well and are available in practically all shades. In comparison with lime-resistant cement or ceramic paints, however, they are less water-permeable. Emulsion paints are definite "film formers", and owing to their large-molecules, are barely able to penetrate into the capillaries of the rendering, and thus are unable to enter into such an intimate relationship with the rendering base as can the mentioned mineral paints, which are more closely related chemically to the rendering. The two properties - high diffusion resistance and film formation - constitute the essential differences between the emulsion paints and the cement-base paints. These qualities are often held responsible for damage to external rendering where emulsion paints have been used.

In practice, damage often occurs when straight lime renderings are covered with emulsion paint too soon after their application. Such damage - destruction of the layer of rendering owing to frost or to thermal stress on surfaces exposed to the sun, especially those painted with dark colours - together with the discovery that in these cases the high lime content rendering has little strength, indicated that the emulsion paint had prevented the penetration of carbon dioxide from the air into the rendering layer and thus delayed carbonation. Investigations carried out at the research laboratory of the Bundesverband der Deutschen Kalkindustrie e.V., Cologne, confirmed this[1]. In lime renderings, with and without various emulsion paints, which had been exposed to the outdoor weather, it was found that a rendering which was unpainted had absorbed 90% of the theoretical maximum quantity of carbon dioxide within half a year, whereas in the case of lime renderings which had been painted, the amount lay between 35 and 70%, depending on the permeability of the paint.

The process of carbonate formation is also influenced by the moisture conditions in the rendering. Since conversion of calcium hydroxide into calcium carbonate by absorption of carbon dioxide (CO_2) is possible only in the presence of water, dry lime renderings cannot carbonate even in a con-centrated CO_2 atmosphere. (Such a case can arise, for example, through artificial drying of a building by the installation of braziers or oil

stoves). Nor is adequate carbonation possible in wet lime renderings, because it is difficult for carbon dioxide to penetrate into the water filled pores and capillaries. Favourable conditions for carbonation are a moisture content of the rendering between 0.7 and 3% by weight[1,2].

It was further found by Piepenburg et al. that naturally weathered lime renderings show higher strength properties than renderings covered with emulsion paints, given equal degrees of carbonation. Piepenburg explains this result as follows: owing to the absorption by the lime rendering of rain water containing carbon dioxide, some of the already formed calcium carbonate is converted into soluble calcium bicarbonate. On evaporation of the absorbed water, calcium carbonate again separates out from this solution. As a result of the continuous alternation of absorption and evaporation of water, coarse crystals and crystal aggregates are formed which have a strengthening effect on the mortar structure. On lime renderings covered with water-repellent surface paints which prevent moistening of the rendering, this kind of strengthening is impossible.

These statements show that the hardening of a lime rendering is a process that depends on influences of very different sorts, and we now understand why the application of a film of paint which prevents the penetration of water and carbon dioxide will be not without effect, generally speaking, on the properties of the lime rendering.

Another question is the extent to which emulsion paints prevent the transmission of moisture from the wall to the outside (humidity of the building or dwelling). It is essential to bear in mind that under the influence of a vapour pressure gradient in a wall from inside to outside, a certain concentration of moisture can occur in the outer layer of the wall behind a diffusion-preventing exterior paint. It should be determined whether, as a consequence of this, damage may be expected in practice under normal conditions.

The answering of the various questions raised is possible on the basis of investigations that simulate practice and which consider the interaction of the structural material of the wall, the external rendering and the exterior paint. Investigations of this sort have been carried out with the support of the Federal Ministry for Housing, Town and Community Planning in the rural test site at Holzkirchen.

First the permeability properties of a number of commercial emulsion paints were determined. The effects of two selected paints on the moisture absorption and emission conditions under natural weather stresses were determined on rendered test walls. The materials used for wall construction were those which could be expected to provide different moisture conditions for the external rendering and the paints, i.e. they were materials with

differing capillary properties (high perforated brick, aerated concrete) and also different initial moisture content ("dry" and "wet" brick masonry). Some of the test paints were applied to the rendering (straight lime or lime-cement rendering) only a few days after the latter had been completed - corresponding to what is often observed in actual construction - while in other cases it was applied only after 8 weeks had elapsed. The reason was to get some idea of the time that should be allowed to elapse in practice between completion of rendering and the application of paint.

Parallel to this series of tests the external walls of two test houses on the test site were coated with three different emulsion paints and with calcimine. For a time during the winter the interiors of the test houses were heated and the air was humidified by the evaporation of water. Material samples were taken at different times from 30 cm thick, hollow concrete blocks in order to determine the moisture content and distribution in the external wall.

Additional details of the test procedure and results are given below.

2. Procedures and Results of Investigations

2.1 Water vapour permeability of emulsion paints

2.11 Test procedure

For determination of the water vapour permeability, various commercial plastic emulsions were applied to felt paper about 1/2 mm thick in various coating thicknesses (1, 2 and 3 coats, always in original undiluted consistency). Circular specimens 19 cm in diameter were cut from the felt paper and fitted tightly so as to form seals into vessels containing a drying agent (silica gel). Above this drying agent, i.e. on the under side of the specimens, a relative humidity of 3% results at the constant temperature of $25^{\circ}C$ chosen for this investigation. On the other side of the specimen there was a constant relative humidity of 70%. Owing to the difference of vapour pressures (16.1 mm Hg) on the two sides of the specimen, diffusion occurs through the specimens, the amount of which can be determined from the increase of weight in the drying agent.

The water vapour transmission coefficient Λ_D (g/m^2 h mm Hg) calculated from the test data, gives the amount of moisture in grams (g) per hour (h) which is diffused through 1 square metre (m^2) at a vapour pressure difference between the two surfaces of 1 mm mercury (mm Hg). The reciprocal of this is called the water vapour transmission resistance (m^{2}h mm Hg/g). The diffusion resistance factor μ indicates how much greater the water vapour transmission resistance of a material is than that of a layer of air of equal thickness.

The values of water vapour transmission resistance and of the thickness of the coats of paint tested were obtained from the differences between the corresponding values on the painted and unpainted boards.

2.12 Results

The results on the relationship between water vapour transmission resistance and film thickness of the emulsion paints tested are presented in Figure 1. From the practically linear relationship between the two test values it may be concluded that the structure and homogeneity of the thin coat (approximately 0.05 mm) are the same as for the thicker coat (0.3 to 0.4 mm), obtained by several applications.

The diffusion resistance factors of the commercial emulsion paints tested are found within a comparatively broad range between $\mu = 500$ and $\mu = 6,000$. On the basis of the relationship between paint consumption and mean thickness of coating represented in Figure 2, for a paint consumption of 0.5 kg/m², which is common in practice, a water vapour transmission resistance between 1 and 10 m² h mm Hg/g may be expected for coats of paint 0.15 mm thick of different manufacture. The values of the transmission resistance of the customary 2 cm thicknesses of external rendering lie in a range between 2.5 and 5 m² h mm Hg/g[3]. The water vapour transmissibility of an emulsion paint thus corresponds in order of magnitude to the transmission of a layer of rendering 2 cm thick.

2.2 Moisture changes in specimen walls exposed to natural weather influences

2.21 Execution of tests and description of specimen

On the Holzkirchen test site a test stand was erected, the west and east sides of which comprised a lattice structure capable of receiving wall specimens 27.5 cm thick (24 cm masonry, 2 cm external rendering, 1.5 cm internal plaster) and 50 cm x 50 cm in area (Fig. 3). The wall specimens were built in wooden frames, which were prevented from absorbing moisture by the application of two coats of bitumunous paint. The joints between the wooden frames and the external rendering were sealed with a plastic filler, so that rain could only penetrate the masonry through the rendering. Two specimens were produced of each wall design, which differed with respect to structural material, rendering and paint. One of the two specimens was exposed to the west, the other to the east, in the test stand. The westerly exposed specimens (the windward side) were fully exposed to the weather. The quantitites of driving rain striking them were measured. The easterly exposed specimens were protected by an overhang; the drying conditions uninfluenced by sun and rain could thus be determined on these specimens.

At suitable time intervals - especially after rainfall - the specimens

were weighed to determine any changes in moisture content. For this purpose they could be rolled onto a balance with the aid of rollers at the bottom. During the winter months of December, January and February, the interior space of the test stand was continuously heated to an air temperature of 20°C. The natural weather studies lasted for a year and a half - from October 1960 to March 1962.

As already mentioned at the beginning, materials were chosen for wall construction which differ radically among themselves in their initial moisture content and in their capillary properties, namely:

1. Perforated brick masonry of air-dry bricks (hereinafter referred to simply as "dry" perforated brick);

2. Perforated brick masonry erected from bricks brought to a moisture content of 10 - 12% by weight (about 50% of saturation) before laying (hereinafter referred to simply as "wet" perforated brick);

3. Aerated concrete masonry erected from 24 x 24 x 49 cm concrete blocks with a moisture content on delivery of 20 to 30% by weight.

As external renderings a straight lime rendering (one part by volume white hydrated lime, three parts by volume sand) and a lime-cement rendering (two parts by volume white, hydrated lime, one part by volume cement, nine parts by volume sand) were used. Both types of rendering were applied in two coats after pretreatment of the masonry with a spray applied rough coat (one part by volume cement, three parts by volume sand). The top coat was smoothed gently with a wooden trowel. On the inside, a lime plaster was applied uniformally to all the specimens. The specimens were constructed, rendered and plastered in the months of August and September, 1960. A pair of specimens (for west and east sides) were prepared for each type of wall in the series without external painting, so that a basis of comparison would be obtained for the effect of emulsion paints on additional specimens of the same type. On some parts of the specimens the paints were applied as soon as possible after completion of rendering, i.e. once the rendering surfaces were no longer visibly moist, so that high absorptivity of the rendering for the water-diluted first coats might be expected. The specified time intervals between the completion of rendering and the application of the paint were two and seventeen days for "dry" and "wet" masonry, respectively.

Immediately after painting all specimens, including the unpainted ones, were exposed to the weather in the test stand. Other specimens of "dry" masonry were first exposed to the weather and were only painted 8 weeks after completion of the rendering. A survey of the tested masonry-rendering-paint combinations is presented in Table I.

The water vapour permeability of emulsion paint A used on all wall specimens is about the average for commercial paints. The paint was applied in three coats in accordance with the directions of the manufacturer (water thinned first and intermediate coats, and unthinned final coat). In addition, an emulsion paint denoted by B (see Fig. 1), which differs from paint A by the presence of a smaller amount of binder and a higher pigment content, was also used on brick wall specimens. This paint was applied in two coats (diluted and undiluted). The rate of consumption of undiluted paint for both types was between 400 and 500 g/m^2.

Finally, measurements were made of the capillary absorption of rendering specimens with and without paint, and before and after exposure to the weather.

2.22 Results

The gravimetrically determined moisture changes in the course of a year and a half of outdoor exposure of the wall specimens are presented graphically in Figures 4 to 7 along with details of the amounts of driving rain striking the west specimens. They show that the rendered specimens without paint as a rule show greater increases of moisture when exposed to rain than the corresponding painted specimens in which some increase of moisture also occurs. Accordingly the paints can be considered water-repellent in the strict sense of the term.

The rather marked increase of moisture noted in the specimens with lime renderings and emulsion paints in the spring of 1961 and 1962 are due to the fact that these paints were partially damaged by frost in winter. This damage was intensified in the following years (see Fig. 15a and b).

In a comparative consideration of the effect of paints on the various wall designs it should be kept in mind that the changes of moisture of the specimens exposed to the west are affected not only by the similar exposure in all cases, but also depend on the different values of the initial moisture content of the specimens, which result in different drying trends. However, by calculating the differences between weight changes of similar specimens installed in the east and west façades, the effect of the different initial moisture content can be largely eliminated and curves of moisture change are obtained which reflect nothing but the effects of the weather. If the wall moisture increases considerably in the course of a year, the protection of this wall design against moisture is not sufficient under the conditions to which it is subjected. In this case a constant increase in wall moisture content during the year can be expected. However, if the wall moisture content remains constant or increases only slightly, in the course of a year, the moisture protection can be regarded as good or adequate.

The difference in moisture content changes between west and east speci-
mens, obtained from the measured results shown in Figures 4 to 7, are given in
Figure 8. For this the moisture-time curves of the wall specimens with lime
external rendering in each case were plotted only for the periods of time
during which the emulsion paints showed no perceptible frost damage. The
representation in Figure 8 is thus suitable for a comparative appraisal of
the effect of paint applied to the different types of masonry or rendering,
as the case may be. For greater clarity in the examination of two paints
(A and B) the areas between the two moisture curves have been hatched. From
these results (Fig. 8) the following conclusions are drawn:

The different water-related properties of the wall material (brick with
high capillary absorptivity and aerated concrete with low capillary absorp-
tivity) and the different initial moisture conditions (dry and wet masonry)
strongly affect the moisture content of the unpainted wall specimens; the
maximum moisture increases during a year occur in aerated concrete masonry,
followed by "dry" and "wet" brick masonry in that order. On the same type
of masonry, moreover, greater moisture increases are obtained with a
straight lime rendering than with a lime-cement rendering (without paint in
both instances). These results confirm earlier findings that the moisture
conditions in external walls frequently exposed to rain depend on the
capillary properties of the masonry material and the conditions of moisture
content of the rendering after its application[4,5]. The moisture increases
during rain are of course reduced by the emulsion paints applied, but the
basic differences due to the properties of the wall masonry material remain.
This is especially clear in Figure 9, where the moisture curves (west-east
differences) of the wall specimens with lime-cement rendering without paint,
as well as those with paint A, are compared.

In specimens of dry masonry the different times between completion of
the external rendering and the application of the paint (2 days and 8 weeks,
respectively) had no general effect on moisture conditions. In the specimens
on which the paint was applied later, greater increases of moisture are
shown, because of the heavy driving rain that occurred during this time (see
Fig. 8), than on similar specimens which had been painted earlier. However,
this result depends on the weather conditions that happen to occur at the
start of the test.

When we consider the total annual moisture content changes of wall
specimens coated with emulsion paint, adequate protection against driving
rain is only obtained if the unpainted wall is adequate, i.e. brick masonry
(dry and wet) with lime-cement rendering. In all other cases, heavy, i.e.
more or less continuously rising, moisture content increases are noted.
Thus, no general or substantial improvement in weather protection can be

attained from emulsion paints of the kind tested, not, at least, to the extent required for external walls frequently exposed to rain. One reason for this is the fact that such paint coats cannot in practice be produced without certain flaws (fine cracks, thin spots, etc.), through which water can enter and that the effect of these flaws can increase as a result of weathering, i.e. changes occur in the structure of the paints which result in greater water permeability. This is evident from the results of the supplementary investigations described below.

Specimens from lime-cement rendering 2 : 1 : 9, 2 cm thick, with area of 20 x 20 cm were prepared without paint, with the two emulsion paints A and B used in the above tests, and with another commercial emulsion paint C (see Fig. 1) and a white lime coating (the latter two coatings were also used in the investigations described in 2.4). Measurements of the water absorption on immersion of the surfaces to a depth of 1 to 2 mm were taken. The means of the water absorption values obtained from 3 individual specimens at various intervals are plotted as a function of the time in Figure 10. The unpainted lime-cement rendering was practically water-saturated after two hours immersion. In the specimens with lime coating there was a slight delay in the water absorption, and in those with emulsion paint coating a considerable delay. The essential point, however, is that even with the latter coating there was a measurable absorption, which can become even greater under the effect of excessive pressure (driving rain), as must be assumed from the results outlined above. The differences between the three emulsion paints tested are very slight.

Following these absorption tests, the specimens were exposed to natural weather conditions, in each case one specimen facing west and another east (spring, 1961). After four months exposure a second such test was carried out under the same conditions as before. The water absorption results before and after weathering, after an absorption time of one hour, are listed in Table II. From this the following points may be noted: on the unpainted lime-cement specimens the absorptivity decreased in the course of weathering, especially in the case of the specimens facing west on which the rain fell more frequently. This can be attributed to the hardening and "moisture treatment" by rain which influences the capillary structure of the rendering[5], and sometimes also to the above-mentioned processes of recrystallization in the rendering[1]. On renderings coated with lime paints and emulsion paints, however, the absorptivity more less increased. This indicates a certain "deweathering", or changes due to the effect of weather, on the part of the paints themselves.

2.3 Investigations of the hardness of external renderings

2.31 Execution of tests

As already reported, frost damage occurs in all lime renderings coated with emulsion paints, under the stated weather conditions, i.e. the strength of the lime rendering was insufficient to resist the frost stresses that occurred. According to the previously cited results of Piepenburg[1] chemical analysis of the degree of carbonation of a lime rendering does not permit an adequate conclusion to be drawn regarding its strength. Therefore a method of measurement was used to obtain numerical results on the hardness of a rendering.

Using a masonry drill (10 mm in diameter) applied with constant force to the surface of the rendering, a hole was drilled in the latter, and the depth of penetration and rpm of the drill are measured continuously. For this purpose a framework was constructed (Fig. 11) in which a slow-speed drill (16 rpm) was made freely movable in the horizontal direction on rollers. With the aid of a pulley, a perpendicular weight (9.4 kg) causes the drill to be pressed with a constant force against the surface of the rendering. A tachometer mounted on the apparatus and a dial gauge make it possible to read the rpm of the drill and the depth of penetration continuously. The number of revolutions per mm of penetration can be regarded as the characteristic value for the hardness of the rendering. Since the area of measurement is small, the result may be greatly influenced by local irregularities in the rendering. It is advisable, therefore, to take several measurements on any given rendering surface and to average the results.

2.32 Results

The results of three individual measurements made by the method described above on a lime rendering with emulsion paint over brick masonry are given in Figure 12. The three curves (rpm as a function of depth of penetration) at first show a slight increase (an average of 0.35 rpm/mm). Then, after a penetration of 16 to 18 mm, there is a definite change in the curve, indicating a transition to a considerably steeper slope. This increase is due to the greater hardness of the sprayed cement plastering at the base of the rendering.

In harder renderings, deviations in the shape of curve are found from time to time owing to the drill striking a comparatively large grain of sand. In such a case the smallest or "most frequent" slope is to be chosen as representative of the hardness of the rendering (Fig. 13).

The results of rendering hardness (rpm/mm) obtained for the lime rendering on the various painted and unpainted wall specimens after exposure

to the weather for 1 3/4 years, are given in Table III. It may be seen from the results that the hardness of the unpainted lime renderings was always somewhat greater than the rendering to which emulsion paints had been applied. However, in the case of lime renderings on dry brick masonry, some of which had been painted immediately after application (2 days) and some only after 8 weeks, no difference can be detected. This may be due in part to the fact that for the renderings painted 8 weeks later, owing to the frequent driving rainfalls, unfavourable conditions for carbonation prevailed (the external rendering was above the optimum moisture content for carbonation purposes practically all the time). This shows, however, that no generally valid conclusions can be reached on the time that should elapse between completion of straight lime rendering and the application of an emulsion paint. This supports Piepenburg's deduction, that cement should be added to all lime renderings which are to be painted with emulsion paints. Piepenburg suggests an addition of at least 20% by weight corresponding to about 10% by volume of the lime component[1].

Under the described test conditions (Section 2.2) all westerly exposed lime renderings, whether painted or not, with the exception of the unpainted lime rendering on aerated concrete, suffered from frost damage. Whether the hardness value obtained for this undamaged, unpainted lime rendering on aerated concrete (1.15 rpm/mm, the highest hardness value measured on the lime renderings) affords adequate assurance of a general avoidance of frost damage, should be determined from further investigations. By way of comparison it may be noted that the hardness index for lime cement rendering (with and without the application of emulsion paints) lies between 10 and 25 rpm/mm.

2.4 Moisture conditions in external walls with emulsion paints

2.41 Execution of tests

The rendered external walls built of hollow pumice concrete blocks and facing the main points of the compass of two extant two-storey test houses (plan 4.5 x 6.5 m) were painted in October 1960. The test houses had been built in 1957 so that the external rendering, consisting of

Cement spray plaster
Undercoat: 2 parts by volume white hydrated lime
            1 part by volume cement
            9 parts by volume sand
Top coat: 1 part by volume white hydrated lime
            1/10 part by volume cement
            3 parts by volume sand

would certainly have been sufficiently carbonated and hardened. On each of

the faces of the two experimental houses two different paints were applied
(vertical line of separation), so that a total of 4 paints could be tested,
namely 3 emulsion paints (paints A, B and C - see Fig. 1) and for comparison
a limewash. The emulsion paints were applied in 3 coats following the
directions of the manufacturer, the first and second coats being brushed on
while the third was applied with a lamb's wool roller. The limewash was
also applied in 3 coats using a brush. Because of the rougher surface
rendering of the structure, the consumption of emulsion paint was somewhat
higher than for the wall specimens described in section 2.2 (500 to 800
g/m^2).

Between the middle of January to the 1st of April, 1961 the interiors
of both experimental houses were kept at a constant temperature of $20^{\circ}C$.
In order to have a large humidity gradient across the wall under the
external temperature conditions during this period (mean value $3.5^{\circ}C$), a
relative humidity of 70% was maintained in the interior by evaporation of
water in the rooms*. Moisture conditions in the differently oriented walls
furnished with different exterior paints were determined gravimetrically
before and after exposure to these conditions from samples of the material.

2.42 Results

From the results of moisture measurements made on the outside walls it
was concluded that the direction in which the wall faces has a greater
effect on the moisture condition than the kind of paint employed. The
moisture distribution values measured on walls facing the same way with
different paints at different places at the beginning and at the end of the
tests in all cases lay within comparatively narrow limits which were
characteristic of the direction in question (Fig. 14). On the north and
west walls against which the rain beats frequently the moisture content in
the outside layer of the wall was higher than that of the inner layer to-
wards the inside of the building, while in the south and east walls this
situation was just reversed. Generally speaking the mean moisture content
was above the practical moisture content that is accepted for pumice con-
crete (about 3% by weight), since in the previous winters the experimental
houses had not been continuously heated.

One conclusion concerning the effect of the tested emulsion paints,
compared to a limewash, on the conditions of wall moisture content can be
derived from the measured results on the north walls of the experimental

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* The difference in water vapour partial pressure between the interior and
  the exterior air was equivalent to room conditions of $20^{\circ}C$ and 50% R.H.
  and outside conditions of $-14^{\circ}C$ and 80% R.H.

houses, which are compared in Table IV. In order to eliminate as far as possible uncertainty in measurements - due to naturally occurring moisture differences in the masonry - the wall moisture content was measured at the beginning and the end of the "simulated dwelling tests", in each case at three different points on the walls. The individual and mean values of the moisture contents of the masonry over its entire thickness (30 cm) and in the wall layer at a depth of 6 cm from the external rendering and in the rendering itself are contained in Table IV. It can be seen that under the influence of heating and humidification of the interior the mean moisture content of the pumice-concrete external wall coated with emulsion paint increased slightly (between 0.7 and 1.5% by weight) in contrast to the whitewashed wall, where the moisture content has remained practically unchanged. Also a migration of the moisture towards the outer wall layer as a result of diffusion was noted in walls coated with emulsion paint (increased 1.5 to 2.2% by weight). The moisture values in the external rendering, however, remained practically the same at the end of the winter period in walls coated both with limewash and with emulsion paint.

This result shows that basically the application of emulsion paint to outside walls reduces to a certain extent the moisture migration caused by vapour diffusion from inside outwards, and this can result in a concentration of moisture in the outer wall layer. Under normal conditions in common types of masonry, this concentration of moisture is not great enough to cause damage (frost damage in the external rendering, blistering and lifting of the paint). This generalization takes into account the fact that in the investigations described, the moisture gradient was greater than normal and that a local concentration of moisture due to diffusion is particularly marked in hollow pumice concrete block walls owing to the comparatively small capillary absorptivity of such material*. The damage mentioned in connection with emulsion paints is probably entirely traceable to the effect of moisture which has penetrated from outside through the film of paint at places where the damage shows (see also Fig. 21 and 22).

2.5 Visual observations

Both on the wall specimens 50 x 50 cm in area and in the external walls of the experimental houses, continuous observations of the changes occurring were carried out during the investigation period. A number of characteristic phenomena were photographed and are commented on below.

As already stated, frost damage occurred on all western oriented wall specimens coated with straight lime external rendering, with one exception.

* In materials with higher capillary absorptivity, moisture differences tend to balance each other by water transport through the capillary.

This frost damage occurred mainly during the second test winter of 1961-62, in which frost set in immediately after rather heavy rainfalls in December (see Fig. 8). The damage manifested itself first of all in the lifting of paint and sections of the rendering at isolated, locally restricted places on the wall. These initial places were probably flaws in the paint at which particularly large amounts of moisture had been able to penetrate during the rainfalls. As the winter progressed the frost damage spread out from these points (Fig. 15a and b), sometimes to the point of complete scaling of the lime rendering, which, subjectively judged, was very brittle. In lime-cement renderings coated with emulsion paints no frost damage occurred (Fig. 16).

Figures 17a and b show the west walls of the experimental houses as they appeared in June, 1962, 1 3/4 years after application of the paint. It will be seen that the whitewash has been almost completely removed by weathering under the extreme conditions of this period, principally as a result of driving rain. The emulsion paints, by contrast, have proved much more durable. Cracks which had existed before painting, mainly along the mortar joints between the hollow pumice concrete blocks, were transferred to the paint and showed up more clearly than before, partly because dirt was deposited in these cracks and partly as a result of the lifting of the paint along the joints owing to frost action. The individual paints tested behaved differently in this respect. The cracks and frost damage appeared most marked in paint C (Fig. 18).

On the less severely exposed north, east and south sides of the experimental houses there were no characteristic differences in the appearance of the paint. Even the limewash here exhibited high stability and covering capacity; after weathering for 5 years the limewash on the east side was worn off only over the coarser sand grains in the rendering (Fig. 19a and b).

The appearance of the emulsion paint on the east and west walls after 5 years exposure to the weather is shown in Figures 20 to 22a and b. The effects of differences in weather exposure are clearly recognizable. While practically no changes have appeared in the paints on the east side, those on the west side show more or less pronounced weathering phenomena. The smallest changes are found in emulsion paint A (Fig. 20a and b) and the most pronounced changes in emulsion paint C (Fig. 22a and b). It is readily understood that the cracks and flaws in the paints formed as a result of weathering, and paint peeling, starting from cracks in the rendering, largely eliminates the water-repellent action of the paint (cf. section 2.22).

3. Synopsis

On the rural test site at Holzkirchen long term investigations were made on the behaviour and effect of emulsion paints on external renderings under natural weathering. The tests were made on wall specimens 24 cm thick with an area of 50 x 50 cm, which were installed in a test stand facing west and east, and in experimental houses (north, east, south and west walls), on which the rendered external surfaces had been coated with various paints. At the same time the water vapour permeability of various commercial emulsion paints was determined.

The wall specimens were constructed of building materials with different capillary properties (perforated brick, aerated concrete) and with different external rendering (straight lime rendering, lime-cement rendering). Two commercial emulsion paints were tested. The moisture changes in painted and unpainted specimens over a period of 1 1/2 years were determined gravimetrically.

Three different emulsion paints were applied to two experimental houses, and for comparison a limewash was also used. In the interiors of the houses normal living conditions with respect to heat and humidity were simulated by heating and by evaporation of water, and the effect of the emulsion paints on moisture conditions in the external walls was studied. At the same time observations were made on changes occurring in the paints over a period of 5 years.

Conclusions

1. The water vapour diffusion resistance factor of commercial emulsion paints is in the range of $\mu = 500$ to $\mu = 6,000$. Taking account of the usual paint thicknesses (approx. 0.15 mm), values for the water vapour permeability are obtained which are of the order of magnitude of 2 cm thick external renderings.

2. Closed paint films of emulsion paints have a relatively high water-repellent action. On external surfaces not exposed to very severe weather conditions the coatings remain durable and resistant for years. (According to available observations, no visible changes were ascertainable after a five-year period of exposure to the water on north, south and east walls.

   Under extreme exposure conditions (exposed sides of buildings), however, the water-repellent action of the coatings diminishes, this being due to flaws in the paint film which become larger in course of time, and also at the formation of fine cracks in the paint which may give rise to - at first locally limited - detachment of the film from its base. The extent, and the development with the passage of time, of this

"weathering" varies considerably from one make of paint to another.
In the case of external walls exposed to extreme weather conditions
the application of an emulsion paint coating will therefore not result
in any fundamental improvement in protection from the weather. In such
circumstances the external rendering, or the wall structure, alone (i.e.
without paint) must ensure adequate protection. If the water-repellent
property of the rendering cannot be considered adequate for the exposure
conditions concerned, this should be augmented by suitable impregnation
of the base before paint is applied to it.

3. Emulsion paints significantly hinder the hardening of pure white lime
   renderings. Such renderings should therefore be sufficiently hard before
   a coat of emulsion paint is applied. However, since the hardening process
   is very greatly affected by the existing weather conditions and the
   moisture conditions in the external rendering or masonry, it is
   impossible to give generally valid indications as to the length of time
   that must elapse between completion of the lime rendering and the appli-
   cation of the paint. Hence pure white lime renderings are unsuitable
   as a base for emulsion paints. When such paints are used, one should
   make it a rule to employ rendering mortars containing a proportion of
   hydraulically hardening binding agent (hydraulic or eminently hydraulic
   lime mortar, lime-cement mortar, white lime mortar with added cement).

4. Because of the diffusion-inhibiting action of emulsion paints, a certain
   accumulation of moisture may occur in the external walls of residential
   buildings in the course of a winter. With the usual kinds of wall con-
   struction and under average conditions the moisture accumulations that
   can be expected to occur are however, not so great that they can be
   regarded as a cause of damage to the paintwork or rendering. As a rule,
   objectionable reductions in the thermal insulating properties of the
   wall are not to be feared either. Damage to the paintwork (blistering,
   detachment of the paint film from the rendering) is, instead, due to
   the action of moisture which has penetrated from outside through
   defective areas in the paint coating.

Table I

Summary of test combinations of masonry, external
rendering and exterior paint

Wall material	External rendering	Surface treatment of rendering	Time between application of rendering and painting
Perforated brick "dry"	Lime-cement rendering	unpainted	-
		paint A	2 days
		paint B	2 days
		paint A	8 weeks
		paint B	8 weeks
	Lime rendering	unpainted	-
		paint A	2 days
		paint B	2 days
		paint A	8 weeks
		paint B	8 weeks
Perforated brick "wet"	Lime-cement rendering	unpainted	-
		paint A	17 days
	Lime rendering	unpainted	-
		paint A	17 days
Aerated concrete	Lime-cement rendering	unpainted	-
		paint A	17 days
	Lime rendering	unpainted	-
		paint A	17 days

Table II

Capillary water absorption by lime-cement rendering
specimens (2 : 1 : 9) in suction tests of 1 hour's
duration before and after 4 months rural
weathering of the specimens

(Orientations west and east)

Surface treatment of specimen (lime-cement rendering)	Orientation of specimen	Capillary water absorption in kg/m^2 after 1 hour	
		Before weathering	After weathering
Unpainted	west	2.75	1.2
	east	2.5	2.0
Limewash	west	0.4	0.9
	east	0.45	1.4
Emulsion paint A	west	0.05	0.06
	east	0.04	0.08
Emulsion paint B	west	0.06	0.08
	east	0.05	0.05
Emulsion paint C	west	0.05	0.07
	east	0.04	0.06

Table III

Hardness indices of lime external renderings with
and without emulsion paint after 1 3/4 years weathering

Wall material	Surface treatment of rendering	Time between application of rendering and painting	Hardness index (rpm/mm) for orientation	
			West	East
Perforated brick, dry	unpainted	-	0.5	0.75
	paint A	2 days	0.35	0.3
	paint B	2 days	0.3	0.3
	paint A	8 weeks	0.3	0.3
	paint B	8 weeks	0.35	0.5
Perforated brick, wet	unpainted	-	1.0	0.75
	paint A	17 days	0.4	0.4
Aerated cement	unpainted	-	1.15	1.0
	paint A	17 days	0.4	0.3

Table IV

Measured values of wall moisture content of north external walls
(pumice-concrete) with various exterior paints at the
beginning and at the end of one winter

(A - C = emulsion paints, K = limewash)

Paint	Time of measurement	Moisture content in % by weight					
		Entire masonry		Outer layer of masonry		External rendering	
		Individual values	Mean	Individual values	Mean	Individual values	Mean
A	7.11.1960	12.7 14.9 13.4	13.7	13.5 15.2 15.5	14.7	-	-
	10.4.1961	14.6 13.9 14.6	14.4	16.0 15.6 17.0	16.2	2.1 1.9 2.2	2.1
	Difference		+0.7		+1.5		
B	7.11.1960	13.0 11.8 13.0	12.6	14.6 12.4 12.4	13.1	-	-
	10.4.1961	14.4 12.6 13.7	13.5	16.7 14.3 14.8	15.3	2.0 1.5 2.4	2.0
	Difference		+0.9		+2.2		
C	7.11.1960	13.0 11.8 13.0	12.6	14.6 12.4 12.4	13.1	-	-
	10.4.1961	16.7 12.5 13.2	14.1	18.2 14.3 13.0	15.2	2.0 2.3 1.7	2.0
	Difference		+1.5		+2.1		
K	7.11.1960	12.7 14.9 13.4	13.7	13.5 15.2 15.5	14.7	-	-
	10.4.1961	13.2 13.4 13.9	13.5	13.7 15.4 14.9	14.7	1.7 2.0 2.0	1.9
	Difference		-0.2		0		
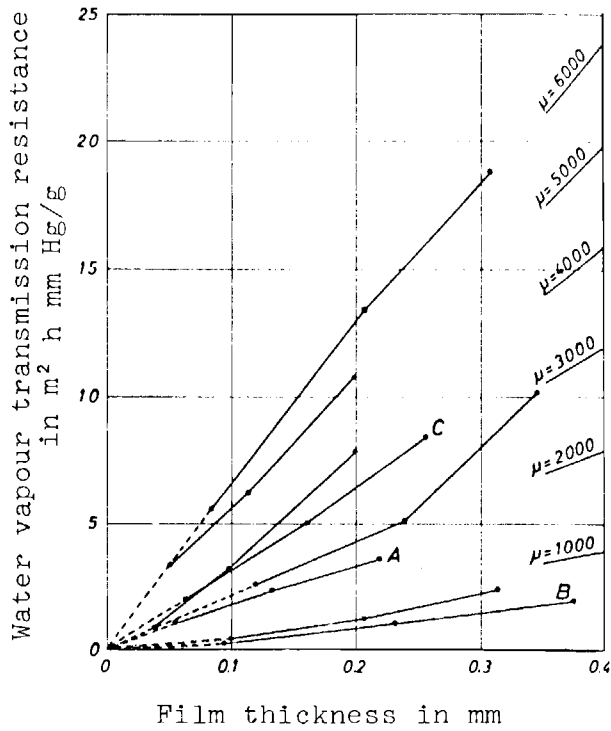
Fig. 1

Relationship between water vapour
transmission resistance and film
thickness of various emulsion paints

The paints marked A, B and C were
also used in the later
investigations
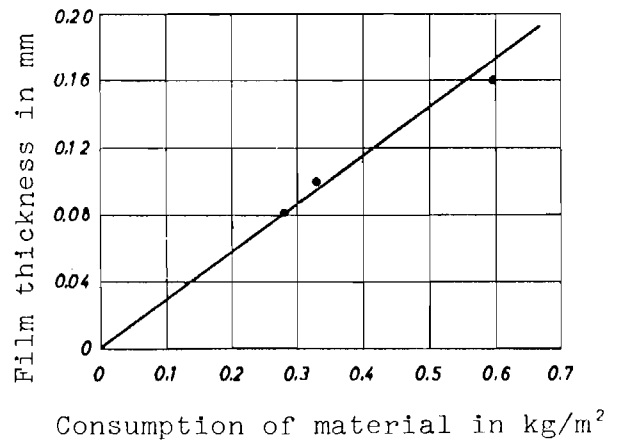
Fig. 2

Relationship between film
thickness of paint and amount
of paint applied
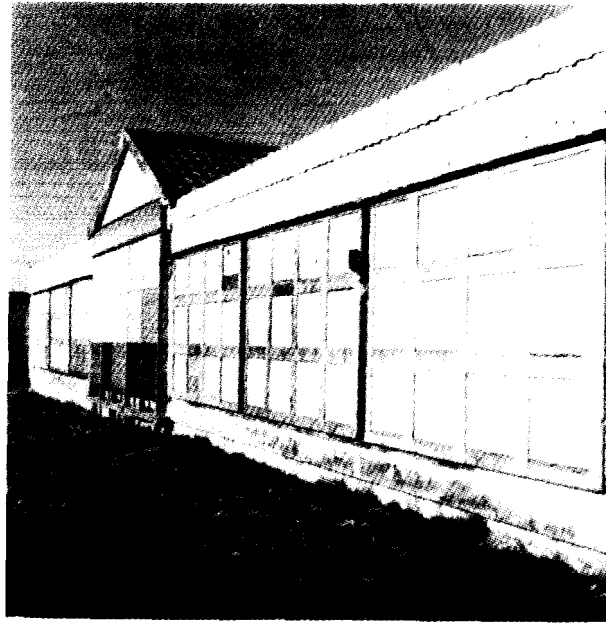
Fig. 3

View of the west side of the test stand for wall
specimens on the Holzkirchen test site

Between the 4th and 5th vertical row from right:
receptacle for measurement of driving rain
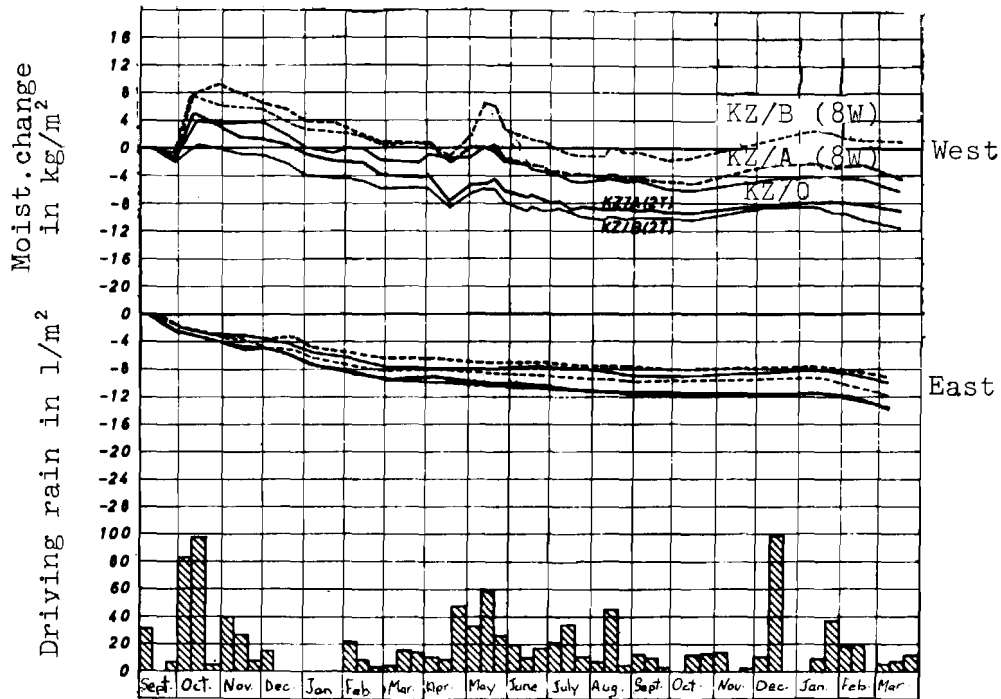
Fig. 4

Changes of moisture content in the westerly and easterly
exposed wall specimens of "dry" perforated brick masonry
with lime-cement rendering (KZ) without (o) and with paints
A and B applied two days (2 T) and eight weeks (8 W)
after completion of rendering
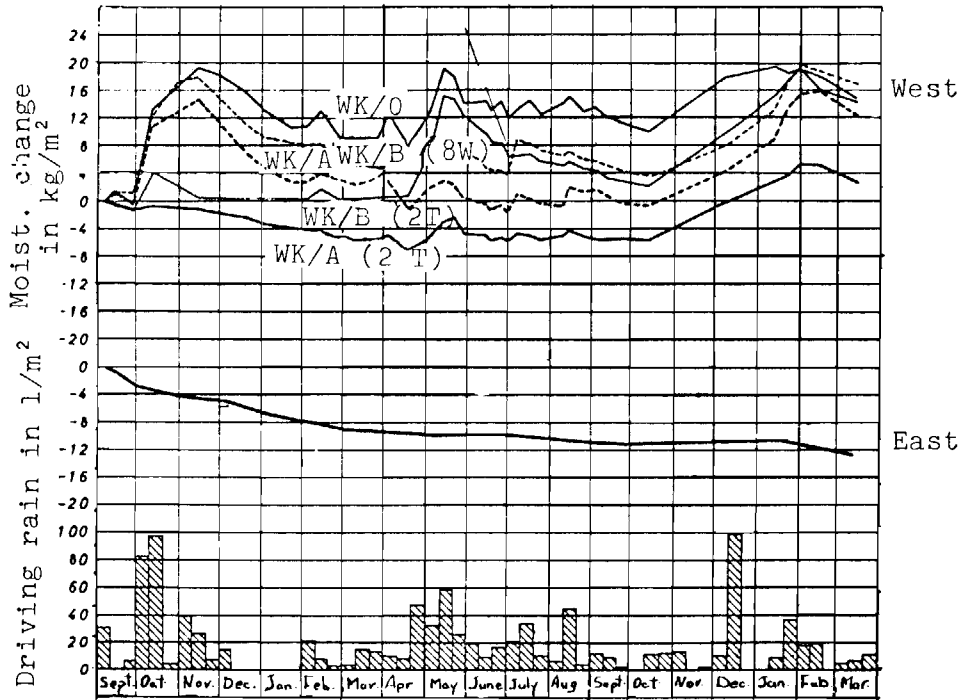
Fig. 5

Changes in the moisture content of the westerly and
easterly exposed wall specimens of "dry" perforated
brick masonry with lime rendering (WK) without (o)
and with paints A and B, applied two days (2 T) and
eight weeks (8 W) after completion of rendering

In the moisture curves of the easterly exposed
specimens no appreciable differences are found and
therefore a mean moisture curve is plotted
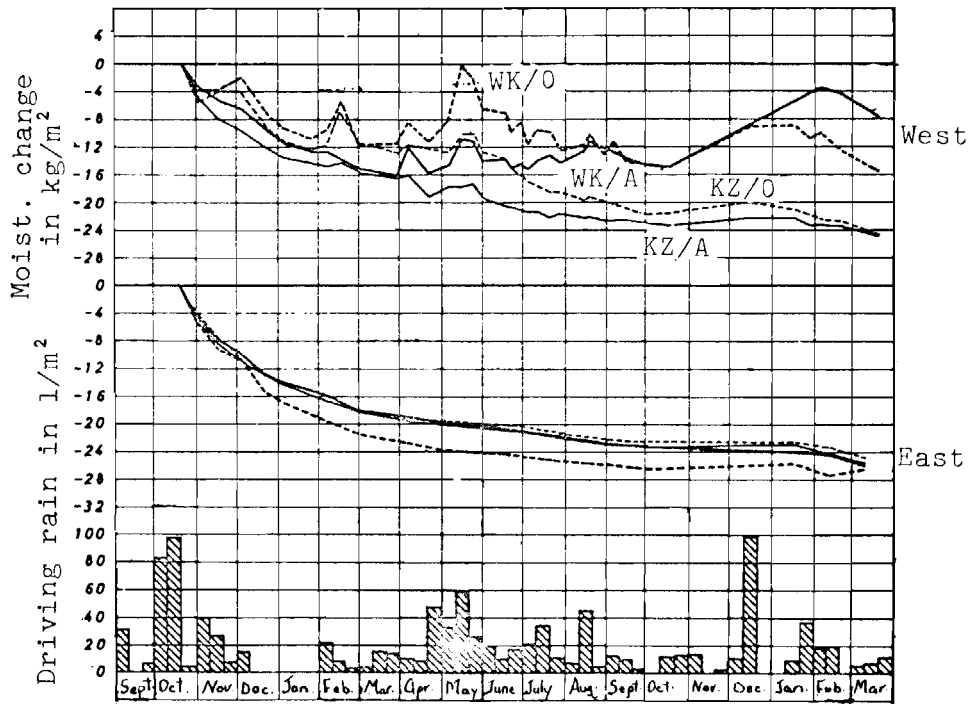
Fig. 6

Changes in the moisture content of the westerly and
easterly exposed wall specimens of "wet" perforated
brick masonry with lime-cement rendering (KZ) and
lime rendering (WK) without (o) and with paint A,
applied 17 days after completion of rendering
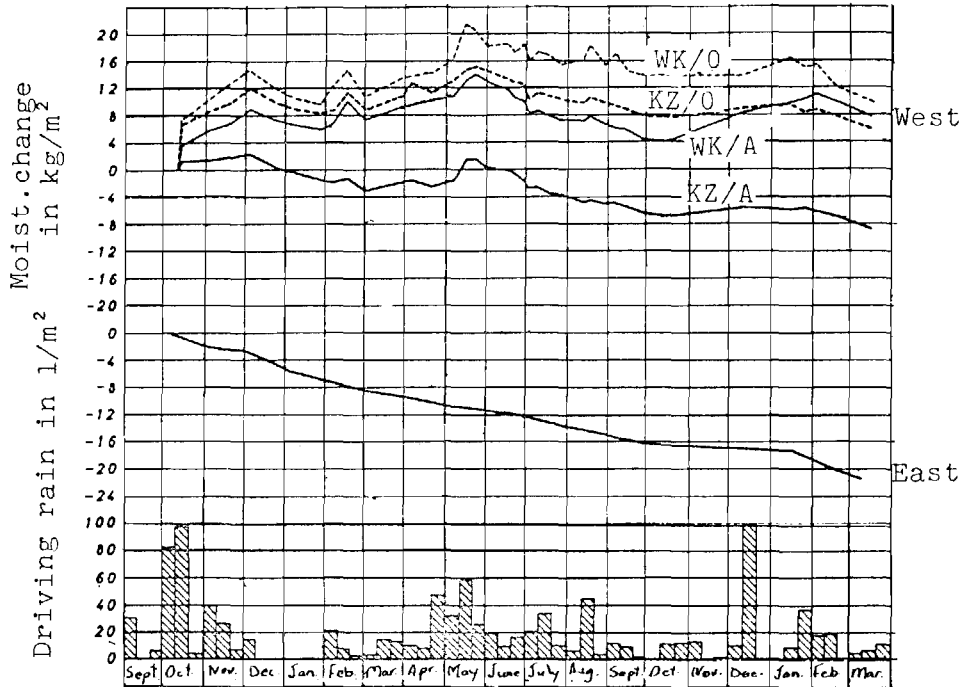
Fig. 7

Changes in moisture content of westerly and easterly
exposed wall specimens of aerated concrete masonry
with lime-cement rendering (KZ) and lime rendering
(WK) without (o) and with paint A, applied 7 days
after completion of rendering

In the moisture curves of the easterly exposed
specimens no appreciable differences are found and
therefore a mean moisture curve is plotted
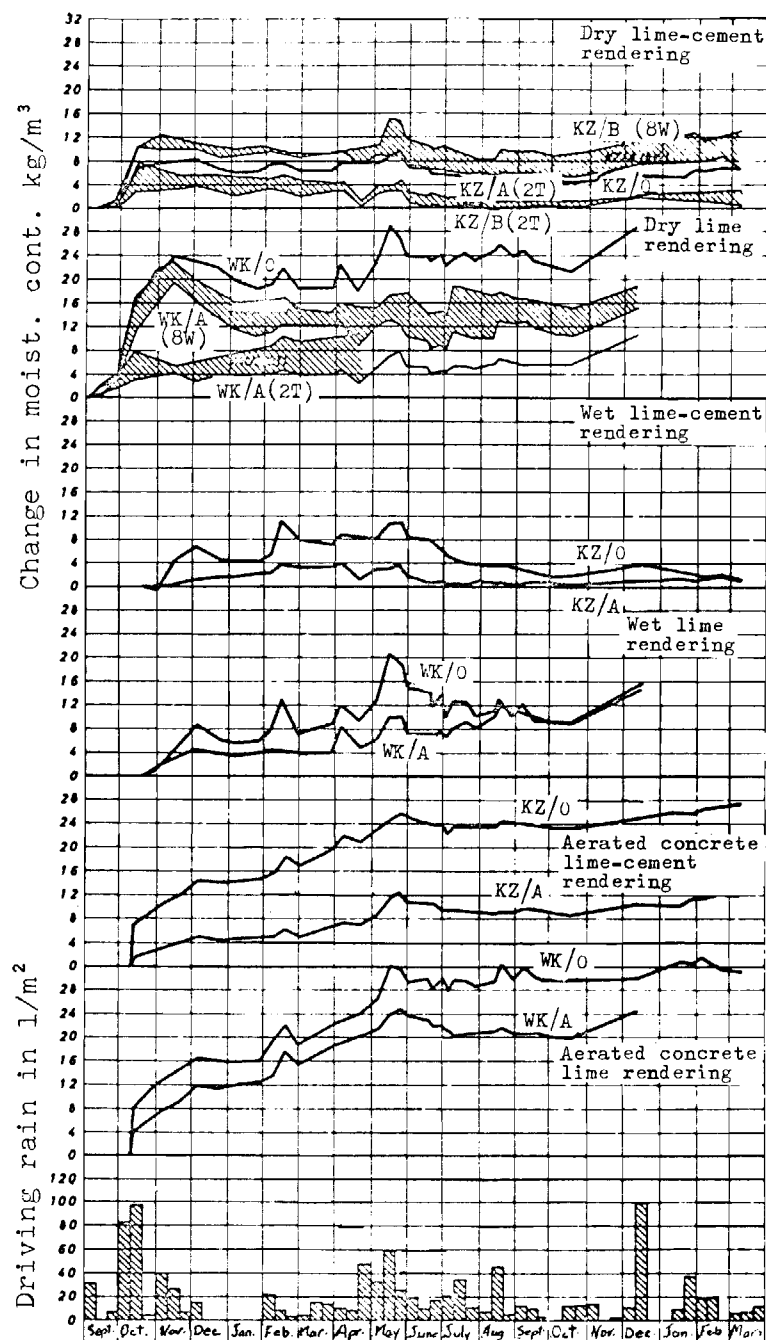
Fig. 8

Changes in moisture content of wall specimens of
different building materials with lime-cement and
with lime external renderings without (o) and with
emulsion paints (A and B), brought about by the
effect of weathering (west side)

The figures in brackets give the time between
completion of the rendering and application of the
paint (in days (T) or weeks (W))
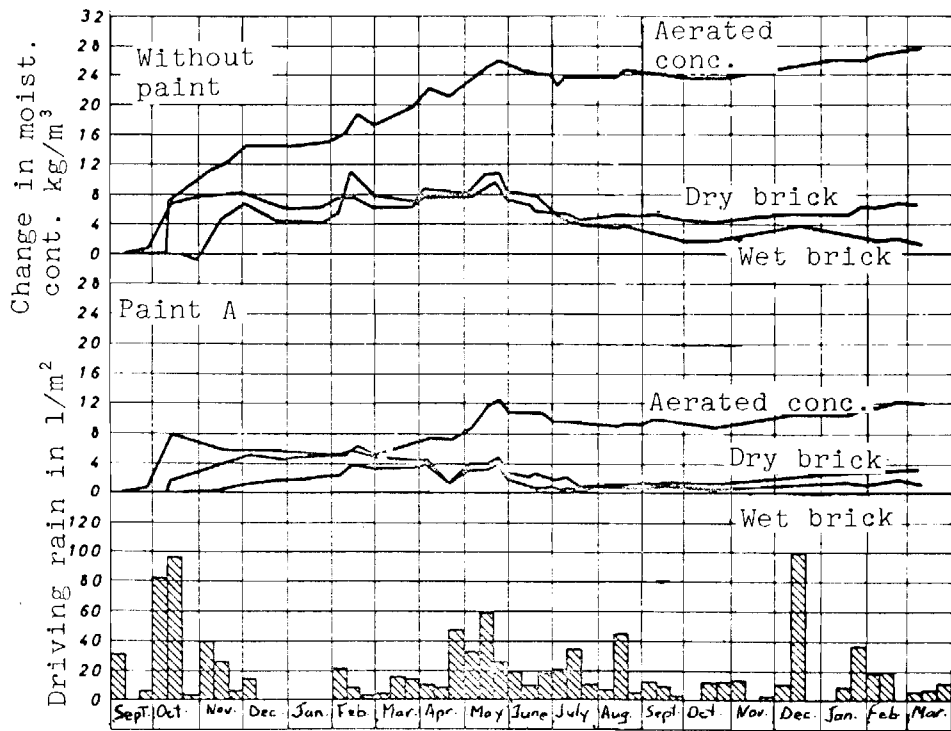
Fig. 9

Changes in moisture content of wall specimens
of different building materials with
lime-cement external renderings without and
with emulsion paint A
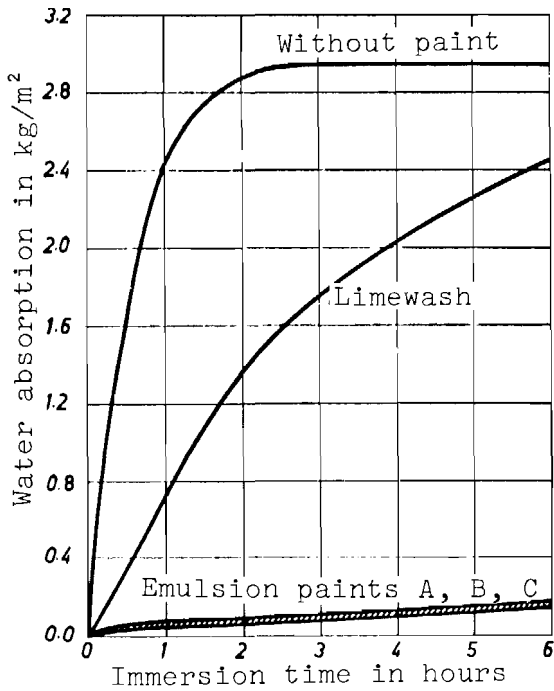
Fig. 10

Capillary water absorption as a
function of the time determined
from specimens of lime-cement
rendering without paint and with
coats of whitewash and
emulsion paints

Mean values from measurements
on three individual specimens
in each case
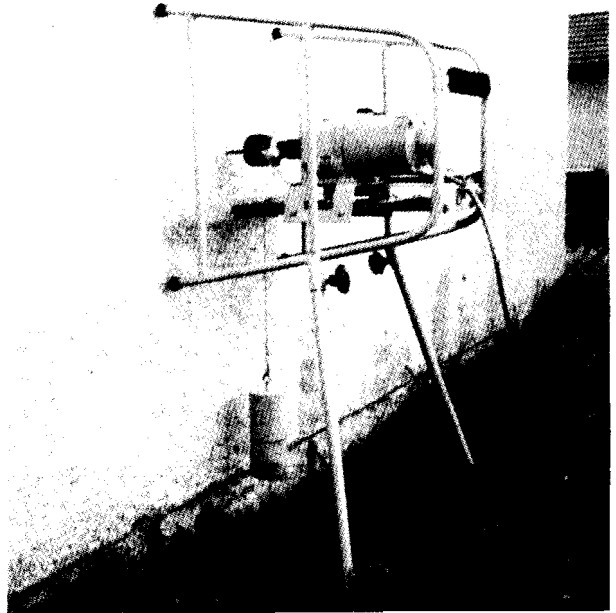
Fig. 11

Instrument for determining
the hardness of a rendering
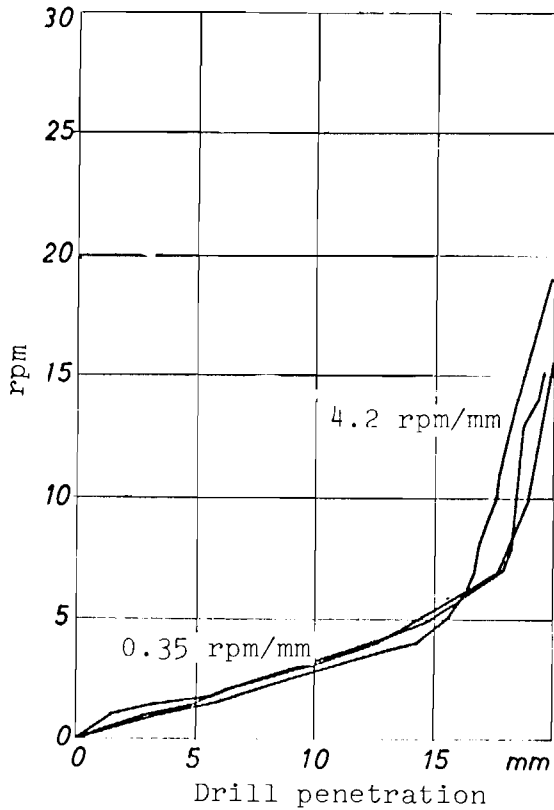
Fig. 12

Relationship between rpm and drill
penetration into a soft lime
rendering (with surface painting)

The slope of the curves after
the drill penetration of 16 to
18 mm is due to the cement-
spray plaster (rough coat)
at the base of the rendering.
The results at 3 different
measuring points agree well
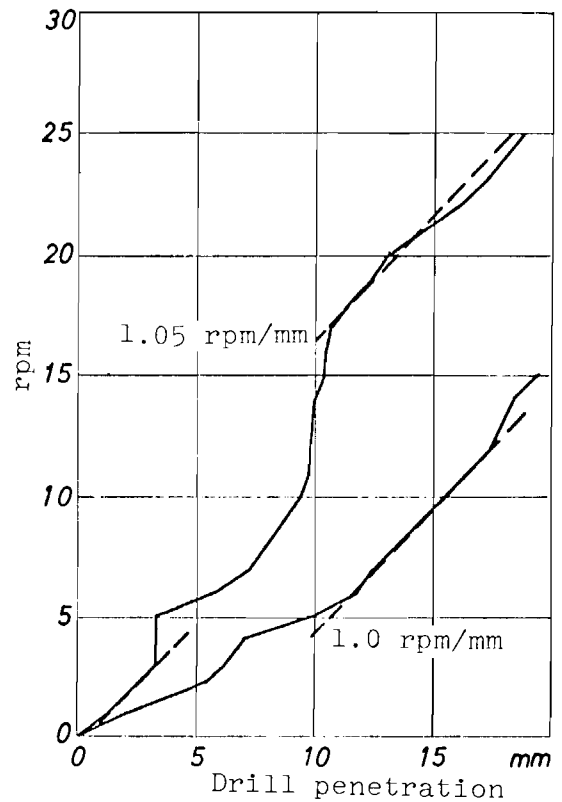
Fig. 13

Relation between rpm and drill
penetration for a harder lime
rendering (without
surface painting).

The irregularity in the
shapes of the curves
(steeper slopes) are due to
the fact that the drill has
encountered a comparatively
large grain of sand. For
evaluation purposes slopes
indicated with the broken
lines are used (1.05 and
1.0 rpm/mm)
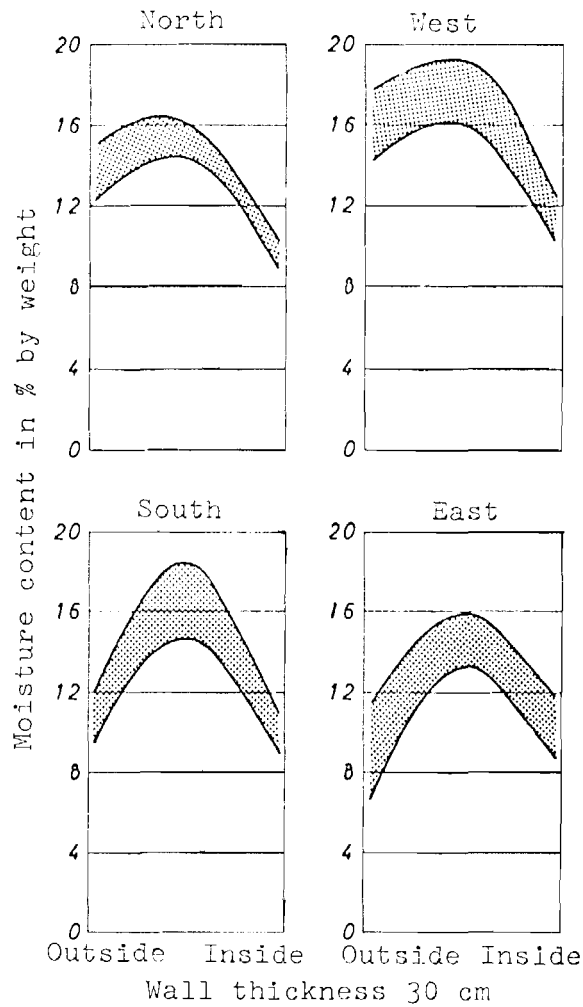
Fig. 14

Moisture distribution in outside
walls of experimental houses constructed
with 30 cm thick hollow pumice
concrete blocks

Average ranges of measurement
over the testing time
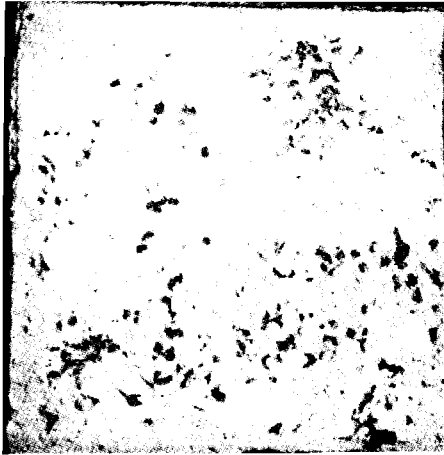
Fig. 15a

Frost damage on a wall specimen
with lime rendering and
emulsion pain

Condition in January, 1962

Fig. 15b

Frost damage on a wall specimen
with lime rendering and
emulsion paint

Condition in April, 1962

The three drill holes in the
upper part of the surface of
the rendering were made in the
course of hardness measurements

Fig. 16

Wall specimen with lime-cement
rendering and emulsion paint

Condition April 1962, after
1 1/2 years of weathering
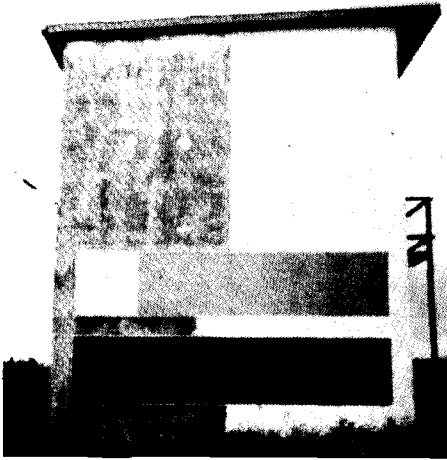
Figs. 17a and b

The west sides of the
experimental houses with
different paints 1 3/4
years after application

a: Left limewash, right
emulsion paint A (on the
lower half of the west
wall, paints of different
colours were used in
order to measure the
resulting surface
temperatures)

b: Left emulsion paint C,
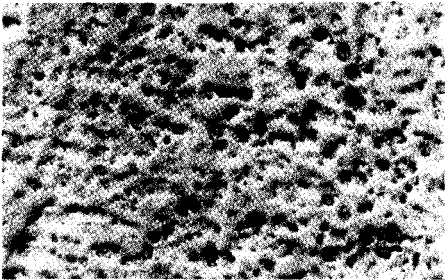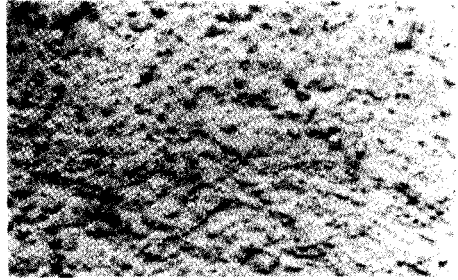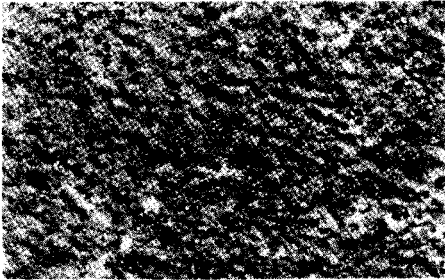right emulsion paint B
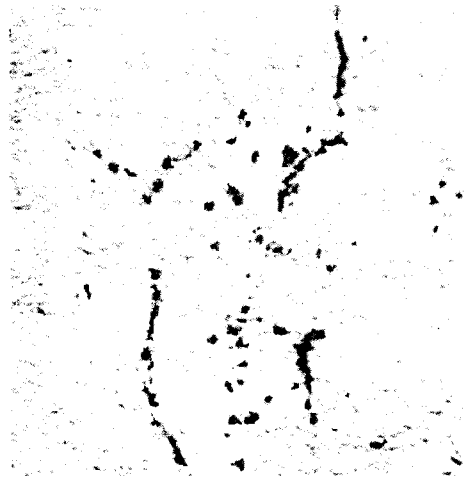
Fig. 18

Close-up of the west wall
of the experimental
house with paint C,
1 3/4 years after application

Owing to frost action the
paint has peeled primarily
along cracks in the
rendering (masonry
joints), but also at
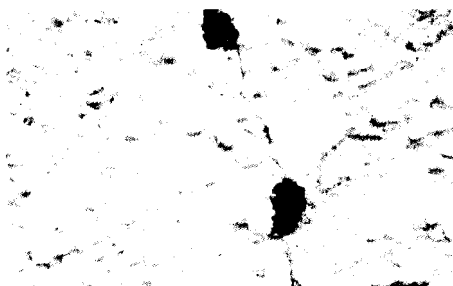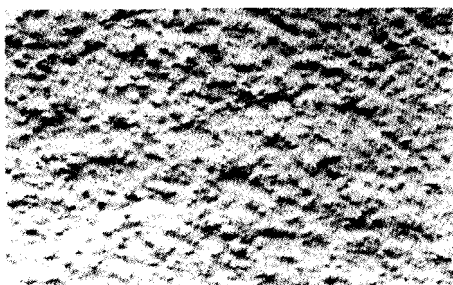other failures in
the paint
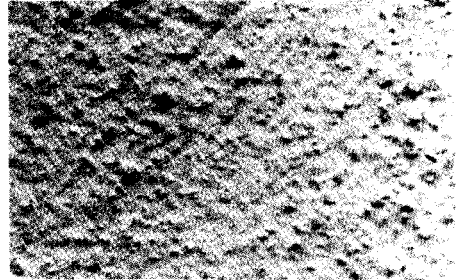
Figs. 19a and b

External rendering with limewash,
5 years after application (June,
1965) on the east side (a) and on
the west side (b) of the
experimental house

On the west side the limewash
has almost completely worn off,
while on the east side it is worn
off only on projecting,
coarser sand grains

Figs. 20a and b

External rendering with emulsion
paint A, 5 years after application
(June, 1965) on the east side
(a) and on the west side
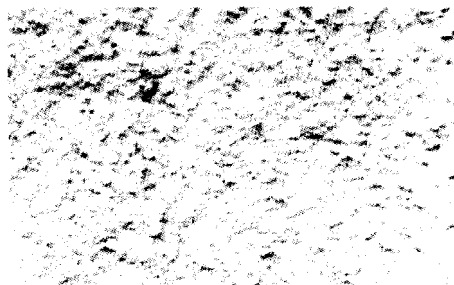(b) of the experimental house

On the west side the film
of paint became more porous
during weathering (flaws in
the paint)

Figs. 21a and b

External rendering with emulsion
paint B, 5 years after application
(June 1965), on the east side
(a) and west side (b) of the
experimental house

On the west side fine cracks
appeared in the paint in the
course of weathering and scaling
of paint occurred starting from
cracks in the rendering

Figs. 22a and b

External rendering with emulsion
paint C, 5 years after application
(June 1965), on the east side (a)
and west side (b) of the
experimental house

On the west side, in the course
of weathering fine cracks
appeared in the paint and scaling
occurred starting from cracks in
the rendering and flaws in
the paint