

General Report on Rain Penetration

By ØIVIND BIRKELAND
Norwegian Building Research Institute

Norges byggeforskningsinstitutt

NORWEGIAN BUILDING RESEARCH INSTITUTE



s 620, 193, 19

B

3-4

930689/ex 3

GENERAL REPORT

RAIN PENETRATION

Ø. BIRKELAND

Norwegian Building Research Institute, Oslo
Norway

INTRODUCTION

The following report is based on the 6 papers submitted for this Symposium and on the experience of the CIB Working Commission on Rain Penetration, partly also on experience from the CIB Working Commission on Large Concrete Elements.

The CIB Working Commission on Rain Penetration has adopted the following definition of rain penetration: "By rain penetration is meant that rain-water penetrates into a wall either through the surface of the wall, or due to leakages at windows or similar installations. It is not necessary that the water penetrates so far that it may be discernible on the inside of the wall".

All the authors who have submitted papers for this Symposium seem to be in agreement with the above cited definition of rain penetration.

To give a fairly complete picture of our knowledge concerning rain penetration, it is necessary to know the stresses (driving rain and wind) to which the wall is subjected, the weather conditions at a meteorological station which determine the onslaught on a wall, and what happens in the wall when subjected to driving rain and wind.

Because of our lack of theoretical knowledge about the forces governing the transportation of water in a wall, it has been necessary to imitate in a laboratory what takes place when rain and wind impinge on a wall. Further experience has been collected from test houses and from failures due to rain penetration.

And finally the aim is to design walls which are impervious to rain penetration.

METEOROLOGICAL FACTORS

In his paper 3 - 4 Mr. Lacy (England) has given a fairly complete picture of our present knowledge. He has also collected a bibliography on the theme. Some information is also included in the paper 3 - 5 of Mr. Isaksen (Norway).

4ex

I have, however, in some papers (not submitted to this Congress) seen varying interpretations of the term "driving rain". It seems appropriate to give a definition:

By driving rain is meant rain which, by the wind, is driven on to a vertical surface. Amounts of driving rain are measured both at the meteorological stations and in terms of onslaught on a wall.

a) Observations at a meteorological station

Different gauges for the measurement of driving rain are in use today. Comparisons have been made between the different gauges with the general conclusion that they all catch about the same amount of driving rain.

Direct observations of driving rain are only carried out regularly at a few stations. It is possible, however, on the basis of conventional meteorological observations, by calculation to find figures which can be used as an indication of the amount of driving rain. Based on such calculated figures maps have been constructed for different countries, one which gives direct amounts of driving rain (Norway). Other maps have been constructed on the basis of the "index of driving rain" introduced by Lacy and Shellard (The British Isles, Canada and Denmark). It is hoped that more maps will be prepared on this basis.

The driving rain maps have proved useful in defining areas which are more or less exposed to driving rain and for comparison of experience with wall constructions. They afford, however, only an indication of the amount of driving rain during a year or for a certain period of a year, and the distribution of the driving rain over the period is also important.

Necessary are also observations on the intensity of driving rain. Some observations are known, but there are great gaps in our knowledge on this subject. Lacy in his paper presents figures for the highest daily amount of driving rain ranging from 36 to 77 mm for four different European stations.

Microclimatological conditions are also of the greatest importance. Within the same town, or part of a town, you may have exposed and non exposed sites.

In addition to the amount of driving rain it is necessary to know the wind speed during rain.

As can be seen from Mr. Lacy's paper we have some knowledge of the meteorological factors. Much knowledge is lacking. It is a suitable subject for further research to collect the relevant meteorological data which will facilitate comparison of experience from different parts of the world.

b) Observations of onslaught on walls

Different gauges for measurement of the onslaught of driving rain on walls are in use. A comparison has shown that they all catch about the same. Most of the gauges now in use measure direct driving rain striking the wall.

It is desirable, however, in addition to this to measure the water which runs off the wall. Gauges which measure both direct driving rain and rainwater running down the wall are being developed. An account of the different gauges is presented in Mr. Lacy's paper.

Some research institutions, especially the British Building Research Station, are making observation of onslaught on buildings, and more and more information on the distribution of driving rain over the surfaces of a building has been collected. Our knowledge is, however, still very limited, and there exists here a vast field for further research.

According to Mr. Lacy the onslaught on the wall is only a fraction of the catchment of driving rain at a meteorological station. The mean rate of driving rain is unlikely to exceed 2 mm/h oftener than perhaps once a year. The intensity during a heavy shower, lasting only for a few minutes, may be many times greater.

Driving rain is not distributed evenly on surfaces, but is concentrated, mainly at corners. Raindrops may be carried upwards in strong air currents along the wall-surface.

In addition to the onslaught of driving rain it is necessary to know the wind pressure, that is the pressure drop across the wall caused by wind. Here we have some guidance in observations made with the aim of establishing wind loads to be used in structural calculations. The wind load is, however, not exactly the same as the pressure drop. Here also direct observations are now being undertaken. This too is a proper field for research.

We have also strong air currents up and along the surface of the building. Little is known on such air currents, they are, however, important.

Variations in the rate of evaporation of water from the surface of a wall will somewhat modify the effect of differences in driving rain from one place to another. The evaporation from a free horizontal water surface is often used as an indicator of the meteorological factors influencing the evaporation from a wall surface. As will be discussed later, this is, however, not the most important factor in drying out a wall.

THE MECHANISM OF RAIN PENETRATION

The water moves into or through a wall under the action of different forces, such as capillary action, diffusion, wind, gravity, absorption, temperature differences etc. Our present knowledge of how water moves in the materials of a wall is far from sufficient for calculating the result of water movements. It is, however, to some extent possible to describe in words the influence of some factors on rain penetration.

An explanation of the mechanism is best given by considering two extreme cases:

A solid wall of material with suction without cracks or joints

When rainwater hits a wall surface it is first sucked into the material. If the rain impinges faster than the suction, a water film is formed on the wall, and the rest of the water runs off without doing any harm.

If rain continues for a long time without allowing the wall the necessary time to dry, the result will be that the wall gets more or less filled with water. When this happens, it needs only a short additional rainfall or gust of wind to make the water discernible on the inside of the wall.

A wall of impervious material with cracks or joints (often consisting of different layers)

The different ways of rain penetration into such a wall are:

- a) Rainwater striking the surface forms a film of running water. The water film forms a bridge over all cracks and openings in the wall which are not too large. The wind pressure acts on this bridge, forcing the water through the openings and into the wall. Rain penetration in this way seems to occur when the openings are between 0.1 mm and 4 ... 5 mm. The pressure difference depends on the wind velocity, shape of the building and the design of the wall. The thickness of the water film is important, depending on the intensity of the driving rain, the height of the building and the design of the wall surface.
- b) Capillary action is added to wind pressure when the openings are smaller than approximately 0.5 mm.
- c) The water may also flow into the wall by gravity. In horizontal joints the water will not, owing to surface tension, flow through openings less than approximately 0.5 mm.
- d) In case of high wind velocities, the velocity of the raindrops may be so high that, if the joints or cracks are big enough, the raindrops will pass through the opening, depending on the size of the opening.
- e) Air currents along the wall may carry the water up across thresholds and overlap joints, and into the wall. In overlap joints there is interaction between capillary action and the air current, if the joint is narrow enough.
- f) Local air currents with high velocity may carry small raindrops through a joint or crack. To make such air currents possible there must be openings through the wall.

The most important form of rain penetration is the one mentioned under a).

Rain penetration through walls of existing materials

Rain penetration through walls is often a combination of the forms of rain penetration enumerated from the two assumed extreme cases. Solid brick walls, lightweight concrete walls, concrete walls, mud walls etc. often show a performance similar to the solid wall of a material with suction without cracks and joints. Even in the case of such walls it seems, however, that unavoidable cracks and joints play an important part in rain penetration. For these walls, too, the wind pressure is, therefore, an important climatic factor.

Cavity walls with cracks, faulty joints or weep holes, curtain walls, timber frame walls and windows, show a performance like walls of impervious material with cracks or joints.

When there exist cracks and openings in a wall, the main factor deciding the rain penetration is the thickness of the water film formed on the wall and the wind pressure on this water film. If the openings are big enough, raindrops impinging on the openings may also have an influence.

For a wall of a material with suction the fact that the wall is kept moist by rainwater and not allowed to dry out is enough to fill the wall with water.

Professor Granum (Norway) in his paper 3 - 6 has given results from laboratory tests. Starting from a wet wall, the rate of evaporation is highest the first few days, and in this period much depends upon the exterior meteorological conditions. Later on the evaporation rate seems to be governed more by the transport capacity in the capillars than by the external conditions, provided that the conditions are not extreme. In modern well insulated walls the heat flow through the wall is not enough to supply the necessary heat for evaporation. For such walls the energy must be taken from the outside air.

Thus, for the drying of a wall the transport of water to the surface seems to be the main factor which determines the drying and not the meteorological conditions, extreme conditions such as freezing on the cold side of the wall seem, however, to cut off the evaporation almost completely. The results of Professor Granum's paper are apparently the same as those from test walls which have been kept on a balance, and exposed to natural weather conditions, (Oral reports at meeting of CIB Commission of Rain Penetration). This is also in agreement with Dr. Vos' (Netherlands) paper 4 - 2.

LABORATORY INVESTIGATION METHODS

Because of the lack of theoretical knowledge about the forces governing the transportation of water in a wall, it has been necessary to imitate in laboratory what happens when rain and wind impinge on a wall. Many institutions have used and are using such laboratory tests in their investigations. It is an aim of the CIB Working Commission on Rain Penetration to reach an agreement on test methods,

making it possible to compare the results of the different laboratories. The following is a brief account of the discussions in the above mentioned Commission.

The laboratory tests are as a rule made by placing a test wall as one of the walls in a test chamber, exposing the test wall to artificial driving rain and a pressure drop. The placing of the wall in a wind tunnel seems to involve too great expenses when the tests are designed in such a way that they can give a true picture of a wall exposed to driving rain and wind. So even if such tests have been tried, they are not generally made.

Test panels

Unavoidable differences in workmanship, cracks, etc. make it difficult to reproduce results from tests on masonry test panels. To obtain results which can be reproduced, it is desirable not to use too small test panels. Some institutions are, however, of the opinion that they get better results by using more small test panels, than by using fewer and larger ones. The difference in opinion may be due to the fact that some laboratories mainly are testing renderings (the laboratories preferring small test panels), while other institutions are testing the masonry as such (the laboratories preferring large test panels).

When testing such constructions as curtain walls and concrete element walls, it is necessary to use test walls of such size that all joints between the elements are represented. This means a test wall two-storeys high, and with a width of several elements. Even bigger test walls have been discussed. It seems, however, that most laboratories have for economic reasons restricted themselves to $1\frac{1}{2}$ storey high test panels. It is open for discussion whether the high costs involved in using such big test walls (and test apparatuses) are justified. For joints between concrete elements at least it is obvious that results can be achieved by testing only the joint, and by studying the horizontal joint, the vertical joint and the joint junctions separately. Murphy (England) (in his paper 3-3) has mentioned a special apparatus for this purpose. Separate joint testing has also been used by Isaksen (Norway) (in his paper 3-5). An apparatus for testing of joints has also been used by T.N.O. in the Netherlands.

Amount and distribution of water

The amount of water must be ample, corresponding to conditions on real walls. For masonry walls the amount of water should be at least so big that a film of running water is formed on the surface. For such walls it seems sufficient that the water be supplied in such a way that a continuous water film is running down the wall. In some countries the rain intensity and the suction of the wall material used in masonry walls are such that as a rule no water film is formed. Under such

circumstances it is not sufficient that the water is supplied at the top of the wall. It is necessary to distribute an onslaught evenly over the test panel.

For curtain walls, timber frame walls and windows etc. the thickness of the water films is important. In such walls there may also be open joints where the direct impact of raindrops has significance. In this case it is necessary to have both water running down the wall and water supplied as real rain drops, distributed over the surface and striking at angles, as during actual rain.

When deciding the amount of water, it is necessary to take into account the highest possible intensity of driving rain onslaught and the rain running down from higher parts of the building.

Wind pressure

It is generally accepted that the test panels during tests must be subjected to a pressure drop corresponding to the pressure drop found over actual walls. Curtain walls, windows etc. are often tested with different pressure drops, starting with a comparatively low pressure and raising the pressure by step up to the highest likely pressure drop. For curtain walls, timber frame walls and similar wall constructions it is important that the pressure drop across the different layers of the wall is the same as for the wall placed in the building and subjected to wind. Most institutions have hitherto used a static pressure. One objection against this is that water running down the wall surface will drip off from projecting parts and not be driven on to the wall again. Several laboratories have now introduced gusts in their testing and this has proved to be of importance. It is comparatively easy to obtain this by varying the output of the fan producing the pressure in the test chamber.

On real buildings there will during wind be rather strong air currents up along the wall and partly horizontally along the wall. Such air currents may play an important part for rain penetration through curtain walls etc.

Observation made during the tests

Masonry test panels are as a rule weighed before and after the tests, and sometimes also during the test. During the test observations are made to detect the appearance of damp patches and/or liquid water on the inside of the wall. When the test panel is of a material which makes this possible it is, after the test, sometimes cut into pieces along horizontal and vertical lines and observations are made in order to see how deep the moisture has penetrated the test panel. For curtain walls, ordinary timber frame walls and windows, observation is made of direct rain penetration through and into the wall. For cavity masonry walls, curtain walls etc. observations are preferably also made on the pressure distribution in the different air spaces formed by the construction, and the distribution of the pressure drop on the different layers of the wall.

Interpretation of the results

The different laboratories making rain penetration tests have as a rule developed certain test runs, and certain stresses to which the test panels are subjected. They have also collected so much experience from test houses and rain penetration failures that they are able to interpret the results of the tests, and predict the behaviour of the tested wall when used in a building. The experience which makes this possible is, however, chiefly valid for certain climatic conditions for which the experience has been collected. Especially in the case of such walls as solid masonry construction it is difficult from laboratory tests, to predict the behaviour of the wall when subjected to foreign climatic conditions. For curtain walls etc. it is easier to predict the behaviour more generally.

EXPERIENCE FROM TEST HOUSES AND INVESTIGATIONS ON EXISTING BUILDINGS

Very much has been learnt by investigating rain penetration failures in existing buildings and by using test huts. It is mainly on the basis of experience collected in this way that it has been possible for different laboratories to establish an interpretation of their laboratory results in relation to results with walls in actual buildings.

Most research institutions working on rain penetration problems are investigating rain penetration failures and are learning much this way. The CIB Working Commission has prepared a table, giving instructions as to the information to be sought when undertaking examination of damp buildings where rain penetration is suspected. However, very little systematically collected experience has been presented to the Commission, although all the members possess valuable information. The information mostly is not systematically treated. It is, therefore, very encouraging that Mr. Givoni (Israel) in his paper 3-1 has showed how it is possible to collect and treat observations from damp buildings in such a way that he is able to establish the fact that the main cause of dampness in the inspected buildings is rain penetration and not condensation, and also to give an explanation of how water penetrated the wall.

EXPERIENCE WITH DIFFERENT WALL CONSTRUCTIONS

Solid wall constructions (masonry of diverse materials, and concrete)

The experience reported with solid masonry constructions is mainly from countries with considerable rainfall, and rain distributed more or less over the whole year. At the same time the temperature conditions are such that the buildings are heated during part of the year.

The solid masonry wall is a type of wall where rain penetration trouble is most likely to be experienced. A heat flow through the wall is necessary as a help in

transporting the moisture to the surface, where it can evaporate. The general experience from buildings in those parts of the world where buildings are heated is, therefore, that if a solid masonry wall does not have a heated room on the inside, rain water will be collected in the wall until the wall is more or less filled with water. Much could be learnt if experience was reported from tropical countries with heavy and seasonal rains.

Concrete can be made nearly tight against water (permeability tests of concrete have been discussed in the paper 2-10 by Mr. Jiro Murata (Japan) submitted to this Symposium). Experience shows, however, that rain penetration may also occur in in situ concrete walls. This is mainly due to the way in which the work is executed on most building sites, and to cracks.

A considerable amount of research has been made on how to execute masonry walls in such a way that they are as tight as possible against rain penetration. The same is the case with renderings. The result is that we know something about how to make masonry and renderings as tight as possible. The quality regarding rain penetration of masonry, of the joints and of renderings is very dependent on the workmanship. Even with the best workmanship rain may penetrate into a wall, on account of cracks, openings at windows and similar installations.

To give only a brief report on our knowledge in this field would require special report, and I found it correct, therefore, to limit my report to the general remarks given here.

Masonry cavity walls

By cavity walls as discussed here are meant walls consisting of one exterior leaf and one interior leaf not connected with masonry tiers.

Laboratory tests have demonstrated that rain penetration through the exterior leaf is mainly dependent on the pressure drop across the exterior leaf. If the exterior leaf has weep holes or similar openings, the pressure drop will be reduced with the result that less water is pressed into the cavity. (If the blocks used in the masonry are of very poor quality, the suction through the material itself may also be of importance).

In general it has been found that cavity walls are very resistant to rain penetration. A condition is, however, that they are correctly designed and constructed. Rain penetrates as a rule the exterior leaf, but it can escape again at the bottom of the wall (if the cavity wall is properly designed and constructed). Filling of the cavity with an insulating material has been discussed in different papers presented at meetings of the CIB Working Commission on Rain Penetration. Reports of investigations on such walls are given in two papers submitted to this Symposium: Korsgaard - Byberg (Denmark) 3-2 and B.H. Vos (Netherlands) 4-2. There is general agreement that it is safe to fill the cavity with an insulating material which does not transport water over from the exterior leaf to the interior

leaf, and does not absorb water. The most suitable material seems to be water repellent mineral wool.

Water proofers

The use of silicone water proofers has been discussed at several meetings of the CIB Working Commission on Rain Penetration. The result is: A silicone treatment of the walls gives the wall a good protection against transport of water into the wall by suction. That is to say all openings (cracks etc.) must be rather narrow.

But at the same time evaporation is reduced to a fraction of the evaporation which takes place from an untreated wall. The reason is that transport of water through suction to the surface of the wall is prevented which means that evaporation has to take place under the surface of the wall.

A silicone treatment of a wet wall is, therefore, dangerous. The same is the case with a wall in which it is possible for the water to enter through cracks, openings at windows etc. Water in a silicone treated wall is more or less trapped.

Efflorescence on the surface is prevented; but efflorescence may take place just under the silicone layer, resulting in spalling etc.

Joints

Numerous reports on rain penetration through joints (especially joints between large precast concrete panels and curtain wall panels) have been presented at meetings of the CIB Working Commission on Rain Penetration and the CIB Working Commission on Large Concrete Elements. At this Symposium, investigations have been reported on in two papers: Murphy (England) 3-3 and Isaksen (Norway) 3-5. The failures reported on by Mr. Givoni (Israel) 3-1 are also due to faulty joints. It seems now to be generally accepted that the best way of making such a joint tight against rain and wind, is to use a so-called two step tightening. The rainwater is stopped at a rainbarrier open to wind penetration. Behind the rainbarrier is an air space, and behind the air space again the windbarrier. It should not be possible to moisten the wind barrier with rain water.

How to make a good joint between precast concrete panel according to the two step tightening principle may now be considered fairly well known in principle. However, many different designs are possible. A preformed element is used as a rainbarrier in the vertical joint. The preformed element most widely used is a loose baffle. When the wind acts on the surface of the building, air penetrates behind the baffle so that the pressure on either side is equalized. The loose baffle is preferably placed 50 to 45 mm from the external surface and with a distance to the air seal of at least 20 mm. A loose tube has been used as a rain barrier. The British Cement and Concrete Association has introduced a cruciform-section strip. The cruciform-section strip can accommodate a greater over-all tolerance than the

two other above mentioned preformed elements. Mr. Murphy in his paper also discusses other preformed elements, among them a cover strip. It is preferable to reduce the amount of water that reaches the seal. This can be done by a suitable profiling of the surface, thus preventing rainwater from being blown across the surface of the wall into the joint. Protruding edges along the vertical joint give a good protection.

For horizontal joints the most common type of water barrier is an upstand. Behind the upstand is then the wind seal.

Junctions between horizontal and vertical joints are preferably designed in such a way that neither the air seal nor the water barrier is broken at the junction. When using a baffle in the vertical joint, and the horizontal joint having an upstand as a water barrier, the water barrier can be made continuous by lapping the upper and lower baffle, so that the upstand is continuous across the junction.

Buildings have many other joints besides the joint between precast concrete panels. There are joints between sash and frame and joint between curtain wall panels. All such joints are preferably designed according to the two step tightening principle. General principles for designing of joints are discussed in Mr. Isaksen's paper.

According to his investigations it is possible to use an open vertical joint, when this can be made as narrow as 3 ... 4 mm. Such a narrow joint is impossible between concrete panels, and also difficult between sash and frame in large windows.

Curtain wall, timber frame walls

Such walls as a rule consist of several layers. In more exposed places also such walls are preferably designed according to the two step tightening principle. That is to say they will in principle have the following layers: (from exterior to interior side): Cladding or sheathing as a rain barrier, airspace, windtight layer (permeable to vapour), insulation, interior cladding (impermeable to vapour). The exterior cladding forming the rain barrier is ventilated in such a way that the pressure on either side is equalized. Such claddings are also used on other types of walls than curtain walls and timber frame walls, as a protection against weather and as an architectural feature.

Two exterior claddings have been discussed by Isaksen in his paper. One of the claddings is natural stone, which can be used as 3 cm slabs, with 7 mm open vertical and horizontal joints, when there is a 3 cm air space behind the slabs. The other cladding is asbest-cement slabs, which can be used when the joints are open and max. 5 mm wide, when the air space is 8 mm.

This report is not comprehensive with respect to our experience with wall constructions. I have mentioned mainly what I regard as the most interesting development of our knowledge.

FURTHER RESEARCH

Further research seems to be especially important on the following topics:

- a) Onslaught by rain and wind on buildings. It is desirable to know not only the amount of rain but also the intensity.
- b) Observations at meteorological stations facilitating comparison of experience between different regions.
- c) Development of standardized rain penetration test methods making a comparison of results from different laboratories easier.
- d) Development of wall construction which can withstand severe driving rain conditions.

In investigating rain penetration laboratory experiments are performed which imitate what happens under natural conditions. This is because of lack of knowledge on the forces governing the transportation of water in a building material, a topic beyond the theme of this report. I hope the discussions in other sections of this Symposium will bring forward more knowledge also on this topic.